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TERMITES

Identification, biology, and control of termites attacking buildings

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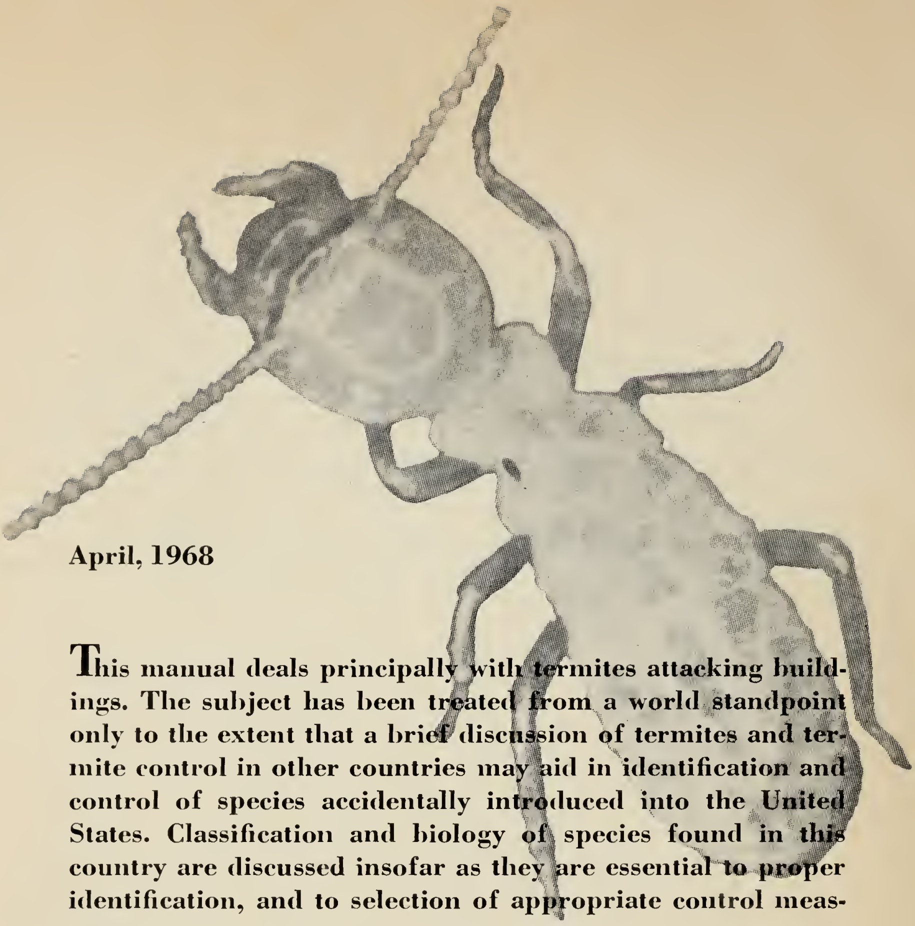

April, 1968

This manual deals principally with termites attacking buildings. The subject has been treated from a world standpoint only to the extent that a brief discussion of termites and termite control in other countries may aid in identification and control of species accidentally introduced into the United States. Classification and biology of species found in this country are discussed insofar as they are essential to proper identification, and to selection of appropriate control measures.

The methods described here for controlling subterranean termites are based primarily on isolation of wood members of the substructure of a building from termites in the ground. Because treatment of soil with insecticides, preferably before or during construction, results in an effective and durable barrier, recommended insecticides, dosages, and methods of application are described. Treatments and alterations recommended after a building is infested are also discussed, and detailed instructions and illustrations take into account various types of construction.

The control of drywood termites, which require no connection with the ground, differs greatly from control of subterranean termites. If infestations are limited and accessible, localized treatment of infested wood members is practicable; if not, fumigation of the entire building is recommended. Because neither treatment protects against reinfestation, materials and procedures for providing such protection are also described herein.

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TERMITES

IDENTIFICATION, BIOLOGY, AND CONTROL OF TERMITES ATTACKING BUILDINGS

The world-wide problem

Termites are responsible for the destruction of a wider range of man's possessions, commodities, and crops than is generally recognized. They are important as agricultural pests throughout the world because they attack a wide variety of field crops, as well as fruit trees and pastures. Termites sometimes infest shade trees, via pruning wounds, severely enough to kill them. As pests of forest trees, however, they are generally of minor importance, although they may do serious damage in certain areas and are especially destructive to forest nurseries. Termites damage an enormous amount of stored food and household commodities. Snyder (1948)[1] listed 120 such items, including dried foods or food products, and materials composed of wood, paper or wood pulp, cloth or other fabrics, hides, leather, rubber, insulation materials, linoleum, and wool. Cellulose acetate was the only plastic found by Snyder (1955) to be immune to attack. Much of the material termites destroy is not used by them as food, but is damaged when they bore through it or when corroded by their body moisture or frontal gland secretions; material may also be damaged by earth packed against it by insects. Termites are of principal importance as pests of wooden buildings, or the wooden parts of buildings. Although destruction by termites is relatively slow, insidious, and spotty, the total of the damage they do places termites among the most important groups of pests, from a world standpoint.

In many tropical regions where these pests are abundant and wood is the predominant construction material, periodic rebuilding of dwellings because of termite damage is common. In tropical areas where control of termites attacking buildings is attempted, the annual cost may be as much as 10 per cent of the value of the buildings as compared with about 1 per cent for farm buildings in the southern states of the U.S.A. (Harris, 1961). In temperate regions, however, the number and cost of habitations may be greater than in the tropics, so that total damage may be much higher. Damage to buildings by termites in the U.S. has been estimated (T. E. Synder)[2] to be $250,000,000 per year, and it is estimated that corrective and preventive work by private termite-control operators costs about $125.000.000 annually (correspondence from Dr. P. J. Spear, Technical Director, NPCA, December, 1963). Assuming that a similar amount is expended by federal and public agencies, it appears that termites cost the U.S. public approximately half a billion dollars per year. In California termite control currently costs substantially more than the approximately $39,000,000 estimated for 1959 (Ebeling, 1959).

Except for specific control measures applying only to certain species (such as extermination of mound-building termites in their nests, or blowing of insecticide dust into the mud tubes of certain species) termite control procedures are remarkably

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[1] See "References" for publications referred to in text by author and date.

[2] News release from the Smithsonian Institution, July 27. 1961.

uniform throughout the world where economic and technological conditions permit. This is particularly true of measures employed to isolate the building against termite attack. A world outlook on the termite problem is justified on yet another basis: many species of termites not occurring in the U.S. are distinctive not only in appearance but also in the evidence of their activities—such as mounds, nests in trees, large galleries above ground leading from the termites' nests to the wood structures they attack, and in the seasons or time of day for swarming. Familiarity with the appearance and activities of potential termite pests may result in detection of accidentally introduced species before they have become so extensively established that eradication is no longer feasible. A case in point is the Formosan termite, *Coptotermes formosanus,* which by the time it was detected in 1965 was so widely established in certain coastal regions of Texas and Louisiana that eradication now appears unlikely. Ironically, this species is much more destructive than the native subterranean termites.

Part 1. FACTORS AFFECTING DISTRIBUTION AND ABUNDANCE

. . . climate, vegetation, soil
. . . adaptation to environment

Termites are found in all tropical and subtropical and most temperate climatic zones. They are increasing their range and density northward, being favored by the accelerated urbanization incident to the "population explosion," particularly in areas where central heating of buildings affords for them a particularly favorable environment for the establishment of colonies. Although termites were able to extend their range to approximately the 10°C (50°F) mean annual isotherm north and south of the equator, only time will tell how much further they may be able to go because of the protection afforded by heated buildings.

Climate, vegetation, and soil factors

The number of species of termites in the various zoogeographical regions of the world has been given by Emerson (1955). There is a marked increase in numbers of species and population density of termites as one approaches the equator. Vegetation may affect the kinds and numbers of termites. They are abundant in pine forests of the southern U.S. but are also diverse and numerous in the desert areas of the southwest, although many of these species are of unknown or limited economic importance. Generally, forestation tends to favor a termite population.

Soil type can also be an influencing factor. Termites are virtually absent in the Mitchell grass plains of Australia, where soils crack deeply and widely in drought periods and waterlog easily during the rainy season, but there is a striking increase in termite population when the desert sandplain is reached (Ratcliffe *et al.*, 1952). In southern California termites are extremely scarce in areas of heavy adobe soil. Soils periodically deeply flooded are also free of termites.

Adaptation to urban environment

The number of termite species and the density of termite population do not necessarily indicate the damage that may be expected in a given area. In the United States, where there are only ten species of subterranean termites (Snyder, 1948), not including the recently introduced *Coptotermes formosanus,* damage to buildings is great because two species, *Reticulitermes hesperus* in the west and *R. flavipes* in the east, are able to adapt themselves readily to dwelling under buildings and infesting them. In Hawaii there are only five species of termites—two subterranean and three drywood species—but two of these, *C. formosanus* and *Cryptotermes brevis,* are serious pests of buildings. In the Union of South Africa there are 126 species of subterranean termites but only the mound-building, fungus-growing *Odontotermes badius* adapts itself readily to nesting under buildings and attacking them. Thus it is more important than all other species combined (Coaton, 1949). It increases in density where virgin land is converted to building sites (as do the principal subterranean species of the U.S.). In Australia, only 10 out of 140 species of subterranean termites attack buildings, and one of these (*Coptotermes acinaciformis*) is responsible for greater economic losses than all the others combined, except in the sparsely settled northern regions where *Mastotermes darwiniensis* occurs. This is due not only to the extensive range and the severity of the attack of *C. acinaciformis* but also to its extraordinary ability to adapt itself to urban conditions and to attack wood buildings (Ratcliffe *et al.,* 1952). In Venezuela, according to termite operator E. L. Moore, *Heterotermes convexinotatus* causes nearly all the damage to buildings done by rhinotermitids.

The ability of a species of drywood termites to attack buildings depends on its moisture requirements. For example, in the eastern coastal belt of South Africa, *Cryptotermes merwei* Fuller destroys much seasoned timber out of doors, but not in buildings. On the other hand, *C. brevis* attacks only dry timber and furniture, and thus is an important pest of all parts of a building not directly exposed to the weather (Coaton, 1948*a*).

Accidental introduction into new areas

One factor favoring the distribution of termites, and which can be expected to increase with increasing world commerce, is the accidental introduction of species into new geographical areas. Gay (1967) lists 51 species of termites, in 5 families, that have been transported to new areas within a country or from one country to another. He states that there is unequivocal evidence of the establishment of at least 17 termite species in new habitats. The drywood termites (Kalotermitidae) are most amenable to accidental distribution because they often infest commonly transported articles such as boxes, crates and furniture, can tolerate relatively low moisture conditions for long periods, and an entire colony is often small (infesting only a small volume of wood) and therefore readily transported for long distances. However, subterranean termites (Rhinotermitidae) have also been distributed extensively by man, the most important example in this country being *Coptotermes formosanus.* Although subterranean termites need a constant source of moisture, they overcome this obstacle in such ways as invading soil of potted plants or timber that has been in contact with moist ground for a considerable period before these materials are shipped, or by infesting wood structures of adequate moisture content in ships.

Influence of modern construction trends

The time required for termites to become established in a building varies according to the species involved, the density of its population in the area, the surrounding vegetation and soil type, the degree of urbanization of the area (a change from rural to urban environment favors many species) and—probably more than any other factor—the type of construction.

Experiments were made near Los Angeles to determine the rate of infestation by termites in newly constructed residences. Soil was treated in lots on which houses with adjoining garages were to be built, using at least 8 insecticides in each of 12 tracts where slab-on-ground foundations were constructed, and in each of 10 tracts were joist-type (raised) foundations were used (Ebeling and Wagner, 1962). On each tract, untreated lots equal in number to treated lots were left as checks. All 22 tracts were on newly developed land formerly planted to citrus or walnut trees. In cooperation with the California Structural Pest Control Board, a study was made of the incidence of termite infestation for 11 years after the lots were treated. On 90 treated and 86 untreated lots inspected on which slab foundations were used, no infestation of subterranean termites has been found. Of the 77 inspected treated lots on which joist-type foundations were used for the houses, one infestation of structural timber was found in a garage (slab foundation) where the ground had been treated with 2 per cent toxaphene, but none in any of the houses. Termites were found in wood debris on the ground under five of the houses. Of the 72 joist-type houses on untreated soil, infested wood debris was found under 7, and termites were also found in a form board that had not been removed after the concrete was poured. Thus in 11 years subterranean termites were found in the wood structure in only one property (in a garage) out of a total of 167 treated and 158 untreated.

Drywood termites, *Incisitermes minor*, were found in 35 of the 325 inspected properties during the 11-year period, in houses or garages or both. All data were combined, as the attics of slab and joist-type houses may be assumed to be approximately equally susceptible to drywood termites. *I. minor* can also attack the substructure of joist-type houses, entering the subfloor area via the foundation vents, but in such cases attics are generally infested also. It is evident that drywood termites infest residential property in southern California much sooner after construction than do subterranean termites (which had in the same period infested only one property). It is likely that infestation by subterranean termites would usually occur much sooner in houses built in old residential areas or on lots from which old houses had been removed. In some densely populated areas where houses are 25 or more years old, subterranean and drywood termites have been found in practically every house or garage at one time or another.

Houses in the tracts discussed above were built (1956) in conformity with modern ideas regarding distances from soil to wood, installation of metal shields, etc.; undoubtedly this accounts in part for the almost complete freedom from subterranean termite attack during the first 11 years. Proper construction is helpful against termite infestation but it is never a guarantee and if termites are abundant it should be supplemented by soil treatment against the subterranean species.

A subterranean termite colony may be very large when it first attacks a building, having developed to that size on subterranean food and surface food that was available before the land was cleared for construction. In areas where such conditions are common a large percentage of houses can be expected to be infested in less than 2 years, and Redd (1957) has observed instances in which damage has been caused before construction was complete. However, if a colony were to originate from a pair of reproductives coming from another area after the building was constructed, 3 or 4 years would be required before the colony would be large enough to produce the first meager supply of swarmers (Pickens, 1934*a*); damage up to that point would be inconsequential.

Despite uniform building codes many construction errors of the past are still being made, and new factors are contributing to continuation of termite infestation (Ebeling, 1959). Some of these are inevitable consequences of mass production and large-scale operations. Perhaps the most important of these factors are:

Increase of concrete slab-on-grade construction. The concrete slab, once believed to be a barrier to subterranean termites, has not proved so. Termites enter through (1) cracks that form naturally in the concrete; (2) cracks formed by the drilling required to secure the sill to the slab; (3) "cold joints" in the "floating slab" type of construction; or (4) around utility pipes and conduits. Smith (1952) found that in 14 years following construction, houses built on concrete slab had only two-thirds as high an incidence of visible termite infestation as did houses with joist-type construction—however, evidence of infestation may not become apparent so soon. Treatment involving slabs is much more difficult and expensive and less reliable; the slab may contain a network of heating and air-conditioning ducts and electrical conduits which can be damaged when the concrete has to be drilled for treatment (which some termite operators refuse to undertake).

The U.S. Public Housing Agency believes that the termite problem is being accentuated in the northern regions of the United States because soils warmed by houses on slab permit termite activity more months of the year (Thompson *et al.*, 1962). The heated slabs are sometimes referred to as "termite blankets."

Bulldozing building sites in forest lands, and building houses on termite-infested soil. When grading hilly land, stumps, logs and brush are often buried in the low areas with earth pushed in from high areas. This covered wood serves as a long-term termitarium and source of infestation of buildings. Decay of the wood may result in subsidence of the earth. This in turn may result in cracks in buildings' foundations, thus providing termites with easy access to the wood substructure.

In southern California, homes are often built in former orchards and trees are commonly left as dooryard trees. These are often neglected, and the resulting deadwood serves as a source of drywood termite infestation (especially in the case of walnut trees). Whole orchards awaiting subdivision are sometimes allowed to die, and drywood termites develop in enormous numbers in the dead trees.

"Do it yourself" construction of floor furnaces, planters or window boxes, doors, steps, patio slab, additional rooms, etc. Much of this is done without knowledge of protective construction. Few planters or window boxes, for example, are properly insulated from the wood members of the house.

Structures erected on loose soil. Settling soil can cause cracks. Also, building sites are often not properly drained.

Improperly constructed foundations. Foundations are seldom reinforced, and it is not uncommon to find many cracks in new foundations. Many foundations are too low and porches and slab areas are often not properly sealed from the foundation. Although foundation design has been improved by modern construction codes, this advantage is sometimes nullified by poor workmanship which may permit voids, chips of wood, straws, etc. to occur in the concrete and prevent its being a perfect barrier.

Improperly installed metal shields. Metal shields should be installed so as to provide protection against termites. Percival (1966) states that "Bolt holes, edges, ends, and torn pieces are not properly soldered or joined to form a continuous metal barrier around the surface of the foundation. In addition, the recommended 2-inch projection at a 45° angle is rarely provided, particularly where porches, garages, and other structures meet the main foundation." Percival also believes that the metal-coated building paper commonly used in some areas is of questionable value because it is easily torn.

Earth-filled porches having only partial seals. Most of these porches have metal flashing which prevents detection of seal failures, and provides space for the entrance of termites through shrinkage cracks because the concrete does not adhere to the metal.

Form boards and stakes imbedded in concrete. Lower foundation form boards and stakes are often found imbedded in the concrete that has overflowed from the more fluid mixture of the ready-mix truck.

Use of water-absorbent building materials on the outside of structures. Use of old and inferior used lumber, and use of new products that do not withstand weathering also contribute to the problem.

Leaving temporary wooden supports under hearths and beneath heavy appliances. These should never be left in place on the ground beneath the building, for wood-to-earth contact is always highly conducive to termite attack, provided the soil is damp.

Brick chimneys not on concrete foundations. There is often an inviting crack on each side of the base of the entrance.

Damaged composition-type pan and sub-drain under the showers. These will leak as soon as the showers are in service.

Higher incidence of leaks where the toilet stool sets on the collar.

Translocation of buildings to new areas in order to make way for new broad roads. Many of the buildings are old and infested with termites or infected with decay, resulting in infestation and infection of new areas.

Condensation problems. These are increasing in cold climates and are resulting in increased attacks by termites and fungi. Also, modern rooms tend to be smaller, with lower ceilings, thus reducing the air available to absorb and disperse moisture released in household operations; additionally, houses are also built more airtight. Condensation caused by refrigeration and air conditioning equipment presents problems.

The use of forest lands for housing tracts in the southern U.S.A. has resulted in great termite danger to houses there—the many varieties of foundation structures, the use of different floor levels, earth-filled flower boxes, or flower beds built up to siding level, etc. pose new and difficult problems. With modern finishes, paneling materials, custom-made paints, and wall-to-wall carpeting, cost of repair and replacement is much greater than in former times. Roofs often have little or no slope, and are built with water traps, gutter systems, and other features conducive to accumulation of leaves and moisture. Subterranean termites often become established in such moist places and work into roofs and walls without having to contact the soil to obtain moisture. The bewildering variety in home designs makes standardization of termite control procedures difficult. Inspection and diagnosis, as well as control procedures, are becoming increasingly specialized and difficult. Thus, the termite operator is being faced with a new concept in his business—that of "prescription termite control" (Redd, 1957).

Harris (1962) has discussed the influence of modern trends on termite control in the humid tropics. Increased building has often resulted in local termite-resistant hardwoods being replaced by imported softwoods, and much use is made of fiberboards, hardboards, and acoustic panels. In some tropical regions houses, which once contained little wood except furniture, are now constructed with wooden floors and wooden ceilings. The result has been an increase in termite problems.

Houses have traditionally been built on pillars in the humid tropics, and this has provided some protection from subterranean termites. Now, slab-on-ground foundations are popular, and in some areas are used exclusively. This accentuates the termite problem. Soil treatment is the best way to protect slab-on-ground structures—but it is seldom practiced.

Increasing urbanization and improvement of living standards in tropical regions has led to the construction of much presumably permanent low-cost housing which can be purchased on a long-term payment plan. With payment plans extending over 20 to 30 years, the need for effective protection against termites has assumed a new urgency. According to Harris (1962), there is need of convincing architects and builders throughout the humid tropics that structures built to provide protection against termites are the most economical from a long-term point of view.

Soil treatment with insecticides can most effectively and inexpensively be applied during the construction period. It is particularly important when slab-on-ground foundations are constructed that the soil first be treated with insecticide, for after the slab is poured this opportunity is lost. The remarkable longevity of certain chlorinated hydrocarbons as termite barriers in soil has been convincingly demonstrated by entomologists of the U. S. Forest Service.

Some building contractors attempt to treat the soil themselves rather than to hire professional termite operators, and in such cases "the chemical, quantity, and coverage are rarely as specified" (Percival, 1966). Percival suggested that termite operators could perform a service by helping contractors and home owners to recognize this problem, and by distributing accurate, timely information on soil treatment to the building trades.

Part 2. IDENTIFICATION, HABITS, AND DISTRIBUTION

. . . subterranean termites
. . . drywood termites
. . . dampwood termites
. . . harvester termites

Termites are small to medium-sized, soft-bodied, social insects having two pairs of wings similar in size and shape. In this respect winged termites can be distinguished from the winged ants with which they are sometimes confused—the hindwings of ants are much smaller than their forewings. Also, termites differ from ants in having the abdomen broadly joined to the thorax whereas in ants the abdomen and thorax are joined by a narrow pedicle ("waist"). The metamorphosis of termites is gradual (they have no pupal stage) in contrast to the complete metamorphosis of the ants. Consequently the young termites are similar in appearance to larger older individuals and may be found crawling about among them.

Although their social organization is more highly specialized than that of other insects, termites are relatively ancient in origin, and are thought to be cockroaches that have evolved and developed a social organization. Termites live in large colonies, each containing distinct forms or castes, such as queen, male, wingless sterile workers (in most species) and soldiers (fig. 1). At certain times of the year swarms of winged sexual forms (alates, winged reproductives, swarmers) leave the old colonies and fly away. These termites are generally black, and the nonreproductives are light-colored. After they alight and shed their wings (at a basal line of fracture), males and females pair off and make a small excavation for a new nest.

Of the six families of termites all but one contain species requiring intestinal protozoa to digest the wood fragments they consume (Kirby, 1934); all North American termites of major economic importance are in this group. Termites of the family Termitidae, containing probably 75 to 80 per cent of the more than 2000 known species of termites, do not possess this type of enzyme-providing protozoa and in fact have few or no intestinal fauna.

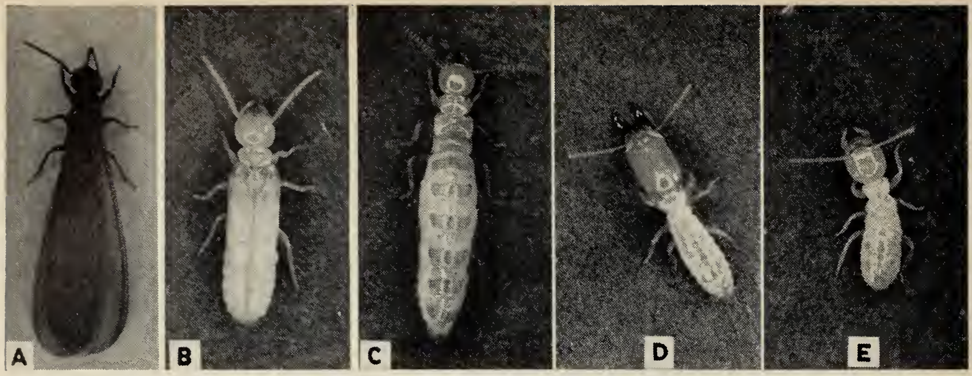

Fig. 1. Castes of the western subterranean termite, *Reticulitermes hesperus*. A. winged reproductive (alate); B. reproductive nymph; C. gravid supplementary queen; D. soldier; E. worker. (Photo, R. E. Wagner.)

Some termites possessing no enzyme-providing intestinal protozoa feed on soil containing partially decomposed vegetable matter, plant roots, etc.; others feed on wood and vegetable debris at least some of which has been subject to fungus action while in the subterranean "fungus combs" of the termites, or while stored as fragments in the warm, humid nest. Some termites feed on the fungus combs themselves, and some feed on sound wood and dried vegetation.

Hendee (1934) invariably found fungi on the burrow walls and in the fecal pellets of *I. minor*, *R. hesperus*, and *Zootermopsis angusticollis* in California. Wood containing colonies of *I. minor* usually showed little structural injury from fungus, but wood containing *R. hesperus* or *Z. angusticollis* usually showed evidence of decay. Experiments with *Z. angusticollis* showed that fungi play an essential role in the natural diet of that species, and the same is true of *Odonotermes badius*, a fungus-growing species (Sands, 1956). Pence (1957) and Lund (1960) demonstrated that *R. hesperus* and *R. flavipes* will attack sound, fungus-free wood. Lund (1965) stated that there was "no clear-cut evidence" that *Reticulitermes* spp. require the presence of other organisms for continued attack. The common wood-destroying fungus *Poria incrassata* gave indication of fulfilling some nutritional requirement, but the way it did so had never been determined. Lund observed that some wood-destroying fungi attract termites, some are repellent, and that there are toxicant-producing fungi.

Esenther *et al.* (1961) isolated a termite attractant from wood invaded by the fungus *Lenzites trabea*. Becker (1964), using five termite species, investigated the attractance of eight compounds formed in wood by wood-rotting fungi; five were generally attractive, and three deterred termites or had no attraction.

Extracts of *L. trabea*-rotted wood induced trail-following by *R. flavipes* similar to that induced by a trail-marking pheromone secreted by a sternal gland of these insects (Smythe and Coppel, 1966).[3] Likewise, a trail-marking scent for *Nasutitermes exitiosus* was isolated and identified by B. P. Moore in Australia (Anonymous, 1967) and was found to be an unsaturated diterpenoid hydrocarbon; only 10^{-8} gram was required to lay 10 yards of trail—other species of the genus *Nasutitermes* followed the trail, but more distantly related species did not. Because diterpenoid compounds occur in certain essential oils, Moore searched for possible attractants in vegetation. He found a substance in the oil from

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[3] Trail-laying and trail-following are common among many termite genera and have been reported for termites in all families except Mastotermitidae (Lüscher and Müller, 1960; Stuart, 1961; Smythe and Coppel, 1966).

the Western Australian sandalwood, *Eucarya spicota,* which attracted *Nasutitermes.*

Of the more than 2000 described species of termites Harris (1961) considered 52 to be serious pests of buildings. The writer has eliminated *Coptotermes exiguus* (Holmgren), said by Dr. T. E. Snyder (correspondence) to be unidentifiable, and has added 18 more species, making a total of 69 building-infesting species, which are found among 6 families, as follows: Rhinotermitidae 33, Termitidae 18, Kalotermitidae 12, Mastodermitidae 1, Termopsidae 2, and Hodotermitidae 3. Divided into groupings of practical significance with regard to control procedures, these building-infesting termites may be thought of as *subterranean, drywood, dampwood,* and *harvester* termites.

Subterranean termites (Rhinotermitidae, Termitidae, and Mastotermitidae)

Subterranean termites are by far the most important pests of buildings, and throughout the world the principal effort at prevention and control is directed against them. From a standpoint of prevention and control, the chief characteristic of subterranean termites is that they ordinarily must maintain contact with moist soil. When feeding on dry wood above ground they periodically crawl down into damp ground through "shelter tubes" ("galleries," "runways") constructed from particles of earth or sand, or minute bits of wood, coated with a gluey substance from their mouths and gullets (Pickens, 1934*a*). (These termites also cover exposed areas of wood upon which they are feeding with a layer of similar material.) After returning to their galleries and nests, the termites can replenish their body moisture, absorbing it through their cuticles. Breaking contact between wood of the infested building and the soil is the principal method of combatting these termites, and often is the only method available.

Weesner (1965) has prepared a termite data sheet to guide American pest-control operators and others who may wish to send her termites, particularly alates collected at the time of flight. Specimens should be preserved in a suitable liquid such as alcohol, rubbing alcohol or formalin. Vials for the collection of termites, as well as the data sheets, may be obtained from Mrs. Lechleitner (= Weesner) at 800 Colorado Street, Fort Collins, Colorado 80521.

Krishna (1966) states that winged forms or soldiers of *C. formosanus* are required for positive identification. He suggests that suspected specimens be placed in 70 per cent alcohol or rubbing alcohol and sent to C. C. Fancher, Plant Pest Control Division, P. O. Box 989, Gulfport, Mississippi 39501. Standard identification forms may be used to record pertinent information, but if they are not available send the following data with the specimens: state, county, city, name and address of property, degree of infestation, name and address of collector, and date of collection.

Rhinotermitidae

This family is made up of small, wood-eating subterranean termites. The most important building pests are the genera *Reticulitermes* and *Coptotermes,* with *Heterotermes, Psammotermes* and *Prorhinotermes* also destructive in limited areas, although with regard to control the last-named genus should be included with dampwood termites. Their nests may be entirely underground in the soil or in portions of poles or tree stumps that are underground or immediately above ground, if the wood is damp. Occasionally they nest in buildings having no connection with the soil, if they can find continuously damp areas.

Rhinotermitidae nests usually consist of a subspherical hollow containing an intricate maze of passages and cells separated by walls of a carton-like material. Some species, such as *C. formosanus*, may construct nests of either sponge-like or paper-like material, made largely of wood residue from their fecal matter, or of soil particles or bits of mortar. Wood-residue nests may be rather fragile; the soil or mortar may be quite hard when dry (NPCA, 1966). Nests may be deep: those of the holarctic genus *Reticulitermes* are often 10 to 20 feet underground. The term "nest" may not be entirely appropriate in the case of *Reticulitermes;* the royal pair and young are usually found in galleries of less formalized construction, which have been excavated in buried stumps, roots or wood debris, or even in large pieces of wood above ground if conditions are suitable. The primary consideration is that the interior of the nest be well protected from natural enemies, and that it must be very humid. Pence (1957), by exposing large numbers of *R. hesperus* to a 48-inch moisture gradient, showed that they preferred a relative humidity of 97.5 per cent. They congregated in greatest abundance at that point.

Figure 2 shows various types of termite nests found in the state of Victoria, Australia. Wilson (1959) described how termites from a tree-trunk colony found and infested three houses and a garage, the latter about 120 feet from the source of the infestation, which was the trunk of a eucalyptus tree. The infested part of each building was the one facing the source of the infestation. Termites had reached the buildings via subterranean galleries, thus location of the infestations was the clue to location of the nest. The tree having the nest in its hollow trunk happened to be isolated, so it was easy to find the source of infestation. In such cases control of a termite infestation can be achieved by destroying the nest. Often, possible sources of infestation are too numerous or the nests may be subterranean—in such cases treatment of the infested building is the only satisfactory solution.

Mound building is uncommon among the rhinotermitids; most species do not provide such clear evidence of the locations of

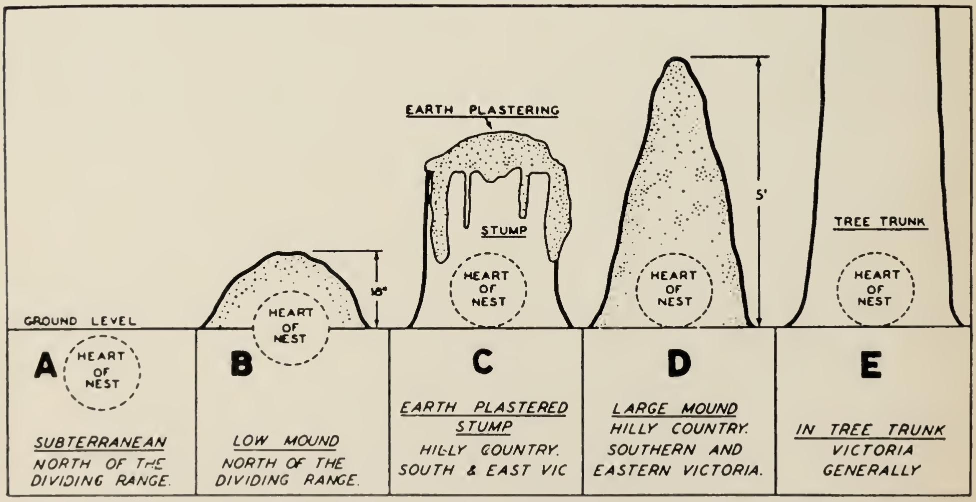

Fig. 2. Types of nests made by termites attacking buildings in Victoria, Australia. A. *Coptotermes acinaciformis; B. Nasutitermes exitiosus;* C, D. *C. lacteus;* E. *C. acinaciformis* or *C. frenchi.* (From Wilson, 1959.)

Fig. 3. Shelter tubes of *Reticulitermes hesperus.* Most of the tubes are exploratory, but the one reaching top of photo is a working tube; it is built more strongly than the others, and reaches wood above the foundation. (From Ebeling and Pence, 1965)

their nests. They generally span the distance between the ground and the first wood members of the substructure of the building by working their way up through intervening wood, or building shelter tubes over concrete foundation walls, etc.

R. hesperus uses at least four types of shelter tubes. *Utility* or *working tubes* form runways through which termites feeding in the wood above the foundations can periodically return to the moist atmosphere of their subterranean galleries in order to replenish lost body moisture. These tubes are wide, flattened, and usually extend from the soil to the wood above (fig. 3). If tubes are broken as rapidly as they are repaired by termites, and termites have no other sheltered passage through which to return to their nests and no other moisture, those above the broken portion of the tube will perish.

Exploratory or *migratory tubes* are similar to utility tubes, but are not as strongly constructed, usually do not reach the wood above, and have small exit holes.

Suspended or *drop tubes* are utility tubes built downward from a wood member to the soil. They are lighter colored because they contain more wood fiber.

Swarming tubes are constructed at swarming time as exits for the winged reproductive forms. They usually extend above ground about 4 to 8 inches, but under particularly favorable circumstances may extend several feet and reach wood members of the substructure. Swarming tubes are often found around floor furnaces or other warm places.

It is highly unlikely that shelter tubes are intended to provide a continuous environment of humid air—it seems impossible that air would remain moist in these dry mud tubes, even when solidly constructed, and sometimes they are flimsily constructed in a loose filigree pattern. Humidity determinations have shown that cavities in joists only 18 inches above the ground, and directly connected with the ground by shelter tubes, had relative humidities practically identical with that of the surrounding atmosphere. It is noteworthy that drywood termites build shelter tubes when they move from one piece of wood to another, although they thrive under very dry conditions.

It is also unlikely that shelter tubes protect termites from light, as the workers are blind and have no aversion to light. In laboratory colonies under glass as many are found in lighted areas as in dark areas, even though they can move about freely. Apparently the purpose of the shelter tubes is to protect termites from natural enemies.

The workers of subterranean termites do not eat all the wood chewed out of timbers. They transport some of it to the rear, and may pile it into a natural cavity in wood or soil, or into a large, unused gallery;

much of it is mixed with fecal plaster and firmly packed along the walls of the gallery.

In the U. S., two native species of *Reticulitermes* are very destructive and are of great economic importance. These are *R. hesperus* in the West and *R. flavipes* in the East. In California the principal species of subterranean termite is *R. hesperus* (the various castes are shown in figure 1). Winged reproductives (alates) are dark brown to brownish-black and have brownish gray wings. Including the wings, they are about 3/8-inch in length and the body, not including wings, is about 3/16-inch long. Another species of *Reticulitermes, R. tibialis,* may be found in some inland areas of California, as in the San Joaquin and Sacramento Valleys and certain high deserts. Weesner (1965) states that the reproductives of *R. tibialis* may be distinguished by their pale, almost whitish wings, with brownish veins in the forearea, as compared with the dark wings of *R. hesperus.* According to Pickens (1934*b*) the most reliable distinction between *R. hesperus* and *R. tibialis* is the short, broad, dark-colored head of the soldier of the latter, compared with the pale, long, narrow head of the soldier of the former. Where the two species overlap in distribution, *R. hesperus* prefers cool, shady, moist places while *R. tibialis* requires open, sunny, drier locations. The two species are equally able to damage wood structures.

After the flight of the winged reproductives of *R. hesperus,* the colony founding pair (king and queeen) may dig some distance to find wood, or may crawl under or into the crevices of a piece of wood on the ground. According to Pickens (1934*a*) an irregular cell is constructed in the wood, usually less than 1/8-inch wide and 1 inch long, in which the eggs are laid. He observed that there are usually less than 10 eggs in the first clutch. From 30 to 99 days were required for hatching. The young nymphs obtain food from the mouth or anus of the parents or workers, and in a week they are also feeding on the brown fecal plaster usually abundant in the nest. In the second instar the nymph contains the intestinal protozoa which enable it to digest cellulose. For the first 2 years most of the termites reach only the fifth instar and are small individuals. Only a colony large enough to supply enough food and a large amount of fraternal feeding will produce the large, well-matured workers and reproductive nymphs of the sixth instar; from 2 to 4 months later the reproductives may attain the seventh instar. Pickens states that workers not falling victim to cannibalism may live 3 to 5 years, and queens probably live much longer.

Pickens (1934*a*) concluded that supplementary reproductives are required for rapid increase in numbers of termites in a colony. When groups of workers and nymphs were separated from the mother colony, they formed a new colony in 6 to 8 weeks, with supplementary queens developed from some of the short-winged nymphs found in every large colony (in addition to the nymphs that develop into flying alates). A supplementary queen can produce more eggs (60 to 80) in a day at the height of egg-laying than the primary queen in the first 2 years of the colony's development.

Termites continually groom one another, by means of their mouthparts, thus obtaining desired secretions or exudates containing ectohormones. The ectohormones are believed to inhibit the formation of additional members of the sex or caste from which they are obtained, thus serving as a regulatory mechanism to prevent a disproportionate ratio of males, females, and soldiers in a colony (Lüscher, 1955, 1956; Weesner, 1956).

Species of *Coptotermes,* present throughout the tropics, have an even greater capacity for destruction than *Reticulitermes.* The Formosan termite, *C. formosanus* Shiraki, long very destructive in Hawaii, was reported from Houston, Texas (NPCA, 1965*b*), and the known infestations were apparently exterminated. The following year it was again found in Houston, Galveston, and in several areas in Louisiana (NPCA, 1966; Krishna, 1966) and appeared to have become firmly established

Fig. 4. The Formosan termite, *Coptotermes formosanus.* Left, soldier; center, reproductive after shedding wings; right, egg-laying queen. (Courtesy of A. A. LaPlante.)

in the United States. On May 6 and again on June 28, 1966, *C. formosanus* was intercepted in packing material in marine cargo in Lathrop, California. On June 14, 1967 two Formosan termites were found in a residence in Charleston, South Carolina.

Because all infestations had been in harbor cities, Beal (1967) believed it almost certain that *C. formosanus* came aboard ship to the U.S. Colonies have been found on boats, ships, dredges, piers, and floating drydocks. Beal believes that *C. formosanus* will eventually have the same range of distribution in latitude in the U.S. as it has in other areas of the world.

The most obvious characteristics distinguishing *C. formosanus* from the native *Reticulitermes* is its larger size and pale yellow body color, the oval shape of the head of the soldier (fig. 4) compared with the oblong and rectangular head of the *Reticulitermes* soldier (fig. 1), and the hairy wings, compared with the absence of hairs on the wings of most of the native subterranean termites (fig. 5). It is well to bear in mind, however, that the soldier bears a close superficial resemblance to that of *Prorhinotermes simplex* (see page 26).

Formosan termites make nests of carton in wood in or on the ground, in hollows they have excavated from tree stumps or posts, or in hollow spaces in the walls, floors, or attics of buildings. Runways from nest to wood have been found as deep as 10 feet underground and 150 to 200 feet long. (If only a portion—including the queen—of a colony is destroyed supplementary reproductives will develop from individuals in the isolated group.) Hrdý (1966) states that besides the primary nest the older, larger colonies of the Formosan termite frequently build secondary nests close to food sources; these nests contain mainly workers, soldiers, and older nymphs. Like the native subterranean termites of the U.S.A., the Formosan termite builds earthen shelter tubes over objects it cannot penetrate, like concrete or treated wood.

C. formosanus flights usually begin before sundown and end before midnight. Warm, sultry evenings, especially when following rain, are favorable for extensive

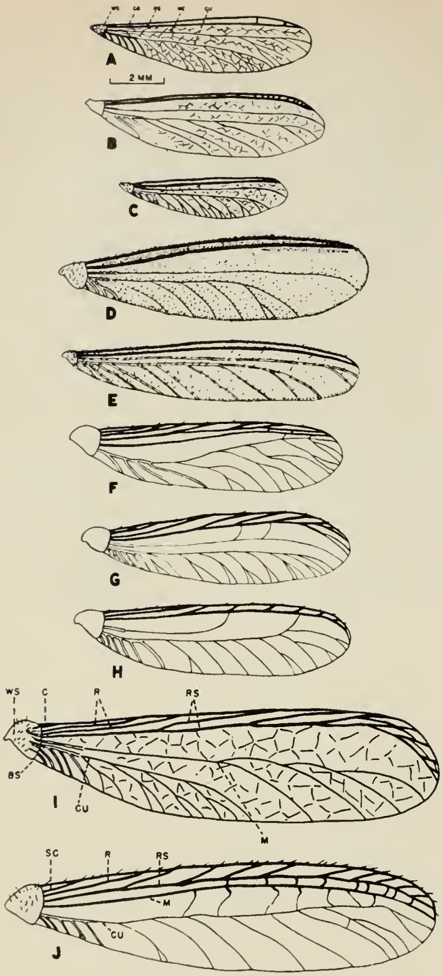

Fig. 5. Forewings of some termites of the United States. A. *Reticulitermes flavipes;* B. *R. hesperus;* C. *R. hageni;* D. *Coptotermes formosanus;* E. *Amitermes emersoni;* F. *Paraneotermes simplicornis;* G. *Incisitermes minor;* H. *Cryptotermes brevis;* I. *Zootermopsis angusticollis* or *Z. nevadensis;* J. *Neotermes connexus* (from Hawaii). (B. courtesy of F. M. Weesner; others from Weesner [1965], permission of National Pest Control Association.)

flights. These insects are strongly attracted to lights. In contrast to *C. formosanus,* native subterranean termites fly during the day, as might be inferred from their black bodies. In California *R. hesperus* generally swarms between 10 AM and 3 PM on the first warm, sunny day following the first rain of the autumn (Light, 1934).

Heterotermes aureus (Snyder) occurs in the desert regions of southern Arizona, southeastern California, and Mexico. It can be very destructive, but much of its damage is probably attributed to species of *Reticulitermes.* The alates are readily distinguished from those of *Reticulitermes* by their pale color (Weesner, 1965).

The Rhinotermitidae are the most destructive to buildings of all the subterranean termites throughout most of the world but in most of Africa south of Sahara certain fungus-growing species of the family Termitidae are far more destructive to buildings (Coaton, 1949) and to agricultural crops (Sands, 1962).

Termitidae

Termitidae are ground-dwelling, mound-building and tree-nesting species. Although Termitidae contains over 70 per cent of the more than 2000 species of termites currently recognized, only 17 species were considered to be important pests of buildings by Harris (1961). According to Weesner (1960) it seems probable that all young pairs nest in a simple cavity in the soil (the copularium) and that the mature nest is constructed by the individuals which these pairs produce. Arboreal nests are usually connected with the soil by shelter tubes, and the entire colony may move into the soil during the dry season.

Because the termitids have no intestinal fauna to aid in digestion (Cleveland, 1924) most of them consume grass, leaves, humus, the manure of herbivorous animals, and decaying wood. The species of one subfamily (Macrotermitinae) have fungus combs in their nests. The spongelike fungus combs, which seem to be an important part of the food supply, are constructed of chewed wood and are built up to fit the chambers of the nest. When fresh fungus comb was added to a diet of filter paper or wood chips, the life period of workers of *Odontotermes badius* was increased from 11 to 55 days (Sands, 1956). According to Coaton (1949), all the fungus-cultivating species in the Union of South Africa are capable of destroying sound timber.

Some Termitidae nest mainly in surface

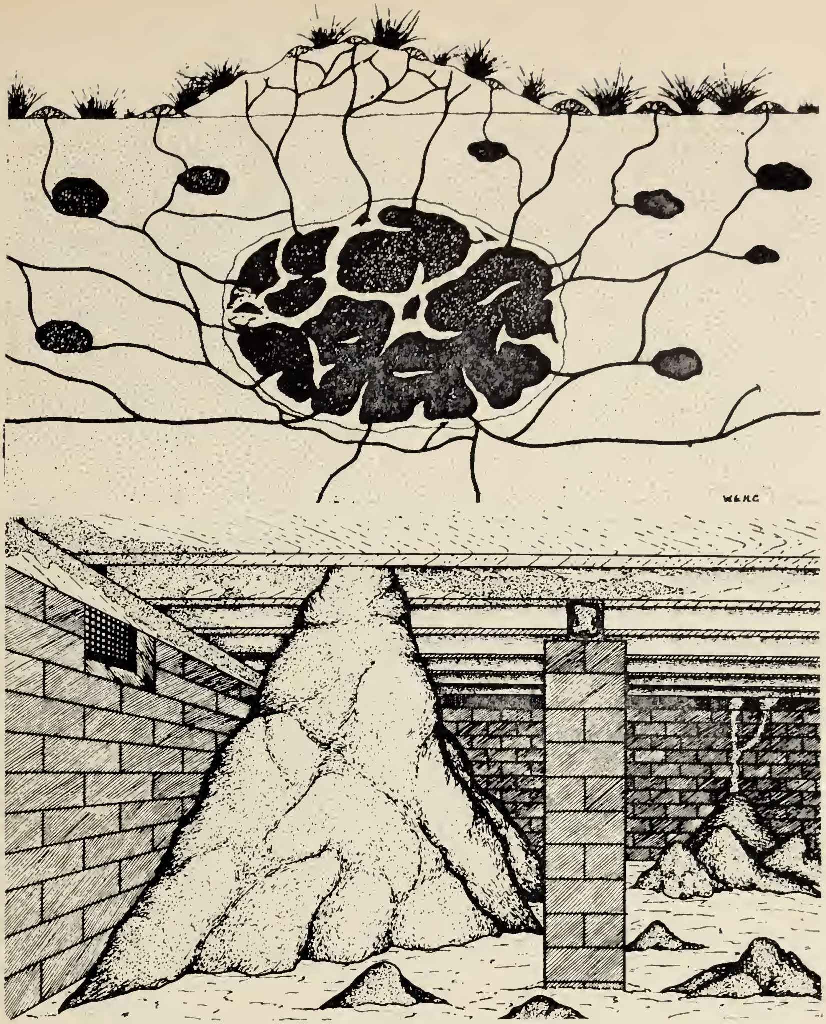

Fig. 6. Mounds, nests and galleries of *Odontotermes badius.* Top, cross section of a mound and the extensive nest and gallery stystem; bottom, external view of mound touching timbers beneath house. (From Coaton, 1949.)

mounds, while others have nests below the surface, some with no mounds (Coaton, 1949). Therefore, with some species connection with wooden parts of buildings above ground may be by means of mounds as well as by access available to other subterranean species. Such is the case with the very destructive *Odontotermes badius* (fig. 6). However, *O. latericius,* which is not a mound builder, reaches wood members as do the rhinotermitids—through foundation walls and piers or through tubes built against the surfaces.

The subfamily Nasutitermitinae contains most of the species that forage in daytime. The name derives from the fact that the head of the soldier is drawn out into a long nasus or rostrum, at the end of which is the cephalic gland, which secretes a substance used for defense. Some species build spherical nests of carton in trees and others build dome-shaped mounds on the ground. In the genus *Nasutitermes,* species in the American tropics and the Far East are predominantly tree-nesting; in Africa and Australia they mostly form mounds on the ground (Harris, 1961). In Australia, mound-building *Nasutitermes exitiosus* is destructive to buildings, fence posts, poles and bridge timbers, mainly in the outskirts of towns and in farm areas (Ratcliffe *et al.*, 1952).

There are some termitids of slight economic importance in the southwestern deserts of the United States (Weesner, 1965). *Gnathamitermes perplexus* (Banks) reaches a length of 5/8 inch, including wings. This species, which is brown, is primarily soil-dwelling but builds extensive earthen workings above ground to cover vegetation, cow-chips, stumps, posts, and other wooden structures. This behavior, plus the superficial damage it can do to wood, results in it being an occasional pest. A similar species, *G. tubiformans* (Buckley) is common in south Texas.

Amitermes spp. are somewhat smaller than *Gnathamitermes*, rarely exceeding 1/2 inch in length, including wings. The alates are dark and even black. The soldiers have mandibles usually less than 75 per cent as long as the width of the head, and the outer margins are strongly recurved from the base to the tip. Unlike *Gnathamitermes*, *Amitermes* spp. do not build extensive earthen passageways nor other structures above ground. However, they attack wood directly, entering at the point where it contacts the ground, and are therefore a greater economic hazard than other desert-dwelling termites (Weesner, 1965). *Amitermes* spp. have been known to girdle and kill young citrus trees.

Mastotermitidae

This family consists of one genus having a single species, *Mastotermes darwiniensis*, indigenous to northern (tropical) Australia. It is very destructive to wood buildings. The winged adult is the largest (over 1¼ inches long) of all the Australian termites. The fanlike extension at the base of each hind wing, known as the anal lobe, and the way the eggs are laid in batches of about 20 in two rows cemented together in a single capsule, make this primitive species unique among termites and afford evidence of the common ancestry of termites and cockroaches. Potentially, this is the most destructive Australian species, but fortunately it is confined to the sparsely populated tropical northern areas.

M. darwiniensis nests are below ground level, mostly in stumps or the hollows of poles or posts. However, nests have been found at a depth of over 40 feet and galleries have been traced through the soil for a distance of over 100 feet.

Drywood termites (Kalotermitidae)

Most of the kalotermitids are larger than the subterranean termites, and they are nearly all wood dwellers. Drywood termites establish their colony and continue to live in undecayed wood having little moisture, and they do not require contact with the soil. They are the most important termite pests in a few areas, such as southern California and the Caribbean area. The most important genera are *Incisitermes* and *Cryptotermes*, the latter being more tropical and also more widespread (in the U.S. it occurs only in Florida and Louisiana). The head of the *Cryptotermes* soldier has a vertical or strongly inclined frontal area (fig. 7), apparently an adaptation for plugging the galleries. The members of this genus are usually much smaller than the *Incisitermes* and their fecal pellets are also relatively small. Galleries of *Incisitermes* are free of debris, while those of *Cryptotermes* are filled with fine wood-powder—this gives them the name "powder-post termites" and causes their damage to be confused with that of powder-post beetles.

In California drywood termites are represented by *Incisitermes minor* (= *Kalotermes*) (figs. 8 and 9), which in southern California is as important a pest as the

Fig. 7. Drywood or powder-post termite soldier, *Cryptotermes brevis.* (Photo, R. J. Pence.)

subterranean termite. It is found under natural conditions as far north as Mendocino County and in the Sacramento Valley. The alate is black, with smoky-black wings having black veins. It may be distinguished from the alate of *R. hesperus* by its larger size (about ¾-inch long), and by the fact that it has a reddish-brown head while *R. hesperus* is blackish throughout.

I. minor may be found in the dead branches of the common California native trees, as well as shade and orchard trees; it is especially abundant in the dead branches of live walnut trees. It attacks utility poles, posts, piles of lumber (particularly redwood) in lumber yards and in residential buildings it attacks principally rafters, ridgepoles, and sheathing in the

Fig. 8. The western drywood termite, *Incisitermes minor.* Top, soldier and nymphs; bottom, alates (winged reproductives).

Fig. 9. Primary queen of a drywood termite, *Incisitermes minor*, and a clutch of eggs. (Photo, R. J. Pence.)

attic, window frames and sills, door and window jambs, door sills, and in the substructure, mainly the mud sills and adjoining cripples or joists.

After the flight of winged reproductives and subsequent breaking off of the wings, a pair of drywood termites will select a place to enter wood. Pairs work together making a hole and then seal themselves in (Harvey, 1934). The hole serves as the entrance to the "royal cell" and is about ⅜ inch deep. The "royal pair" enlarge the hole and the queen lays the first eggs. Generally two to five nymphs hatch from the first eggs and begin an enlargement of the burrow. The nymphs perform the duties performed by the worker caste of other families of termites. The queen then lays more eggs in the advanced part of the main passage of the burrow. Toward the end of the second year after the colonizing pair enter the wood, the colony generally consists of the primary king and queen, one soldier and a dozen or more nymphs (Harvey, 1934). By this time the abdomen of the queen has become broader and longer and she can lay a greater number of eggs (fig. 9). From late spring to late in the fall the primary queen lays from 1 to 12 eggs each 24 hours, for a period of a week or 10 days, then ceases egg laying for a month or more, after which she resumes at the same rate as before. Harvey found that at a temperature of 80°F (26.7°C) and relative humidity of 83 per cent, the eggs in 1- and 2-year-old colonies were hatched in an average of 77 days. He believed that maximum egg-laying capacity is reached when the queen is 10 to 12 years old, then declines rapidly, with the secondary queen appearing to assume the functions of the primary queen. The time required for *I. minor* to develop from egg to alate or soldier was thought to be more than 1 year. Harvey estimated that a colony 15 years old might contain the pri-

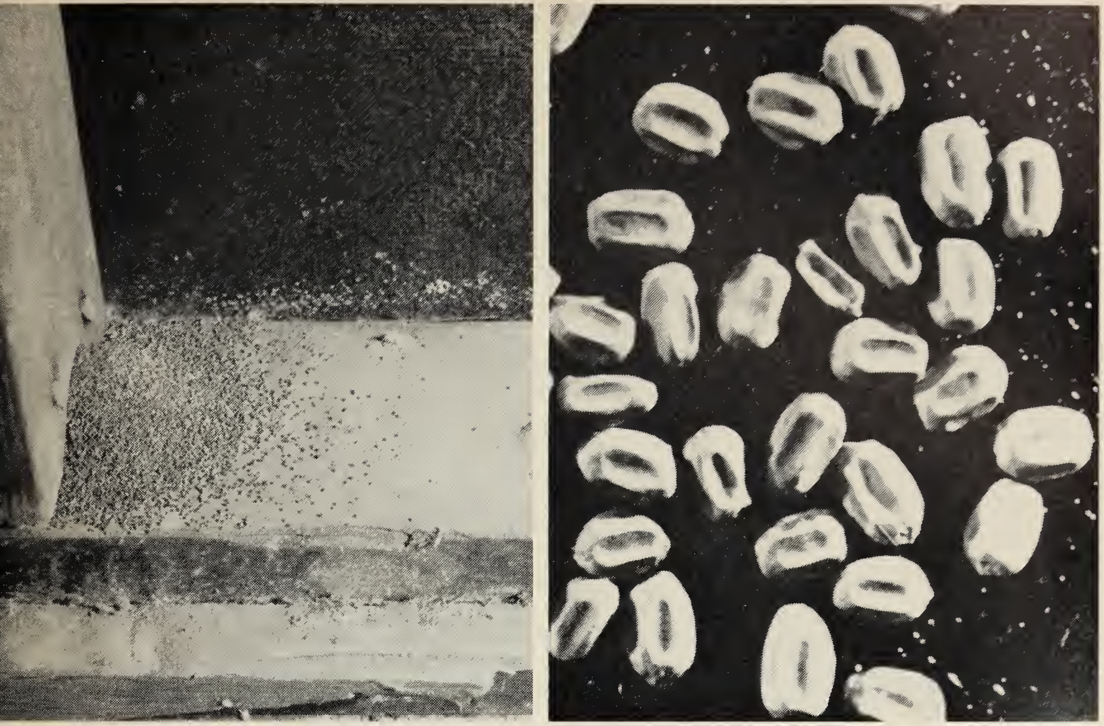

Fig. 10. Fecal pellets of the western drywood termite, *Incisitermes minor*. Left, typical pile of pellets on a ceiling plate; right, enlarged view of pellets.

mary king and queen, one or more supplementary reproductives, 120 soldiers, and 2,600 nymphs. Thus, the colonies are small compared with those of the subterranean termites, which may contain millions of individuals. Damage to buildings, per colony, is correspondingly less rapid and less severe, but proliferation of colonies in a building can result in extensive infestation. Because most kalotermitids can live in dry wood and do not require shelter tubes leading to the ground, they can damage wooden furniture even if it is moved about frequently.[4] For this reason also drywood termites and other nonsubterranean species can easily be dispersed from one area to another.

Drywood termites remain in their feeding area and build no shelter tubes to the ground. Thus, the most common evidence of their activity is the pile of fecal pellets (fig. 10) immediately below the "kick-out" holes or chinks and cracks in the infested wood, particularly where outer walls of the infested wood member have become excessively thin from prolonged infestation. Swarming of the alates (winged reproductives) also indicates infestation.

Drywood termites, and nonsubterranean termites in general, burrow across and with the grain of wood, excavating broad pockets or chambers which are connected by tunnels. Thus they destroy soft spring growth and harder summer growth, whereas subterranean termites attack only the spring wood (fig. 11).

Lighter in color than *Incisitermes minor* is the southeastern drywood termite, *I. snyderi* (Light). It ranges from South Carolina to Florida and west to eastern Texas.

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[4] Pence (1957) found that under extremely dry conditions individuals of *I. minor* in a wood cavity sealed themselves in thoroughly with carton and huddled together to conserve moisture. One individual survived in kiln-dried wood placed in a silica gel desiccator for 245 days.

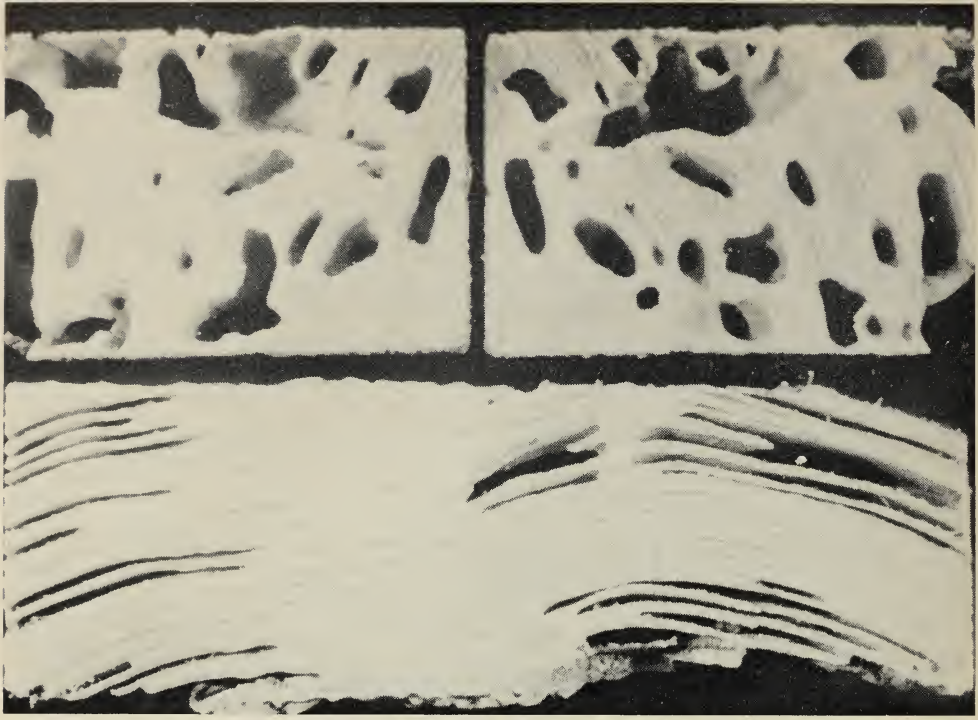

Fig. 11. Cross section of Douglas fir lumber showing characteristic patterns of chambers and tunnels of drywood termites (top) and subterranean termites (bottom).

It is generally not as severe a pest as *I. minor*, but does similar damage to buildings, furniture, and utility poles. Flights occur in May or June in the early evening, after dark.

Marginitermes hubbardi (Banks) replaces *I. minor* at lower elevations and more arid regions of the deserts of southeastern California and northeastern Mexico. The alates are yellow to light brown, and are slightly over ½ inch long when wings are included. According to Weesner (1965) the alates may be distinguished from most other Kalotermitidae of the area by their very pale color, round ocelli, and by the third antennal segment, which is not larger than the second or fourth. The third antennal segment of the soldier is clublike and almost as long as all the succeeding segments combined, making identification easy. The alates emerge at night, usually immediately after a rain, and may collect at lights by the thousands.

M. hubbardi readily invades buildings and is abundant in many areas. Weesner (1965) believes the hazard from this species may increase as cities and suburbs extend into desert areas where it can exist in large cacti and in trees. Light (1933) found *M. hubbardi* very destructive to poles, posts, floors, ceilings, window and door frames, sills, furniture, wood railway cars, etc. in coastal or low-lying towns of the west coast of Mexico. It was much more common in wooden structures than in wood occurring in nature.

Dampwood termites (primarily Termopsidae)

These termites are of minor importance from a world standpoint, but they form a distinct habitat group. Dampwood termites locate their colonies in damp and hence often decaying wood, but once established they can extend their activities into sound

Fig. 12. Pacific dampwood termite, *Zootermopsis angusticollis* (Hagen). A. alate; B. dealate; C. nymph; D. soldier. (Photo, D. A. Reierson.)

and even relatively dry wood. They enter wood directly at the time of swarming and always confine their work to wood. They are occasionally responsible for serious damage to wooden structures, usually in conjunction with fungus. It appears that the species of *Zootermopsis* (family Termopsidae), which are principally confined to western North America, are responsible for most of the damage of economic importance.[5]

In northern California and the Pacific Northwest, *Zootermopsis angusticollis* and *Z. nevadensis* occupy a similar range, the latter predominating in cooler, drier, higher areas. *Z. angusticollis* extends southward along coastal California and eastward along the damp stream beds of foothill canyons and on into the mountains, where it may be found under the bark of fallen trees. Both species are potentially destructive. Infestation of buildings by *Zootermopsis* generally requires wood-to-earth contact, which is not in accord with the standards of modern construction.

The winged reproductive of *Zootermopsis angusticollis* (fig. 12) may be an inch or more long, including the wings; the wings are from ⅞ to an inch long (fig. 5). The body is light cinnamon-brown; the wings are dark brown, heavily veined, and leathery in appearance. The soldiers (fig. 12) are ⅜ to ¾ inch or more long, depending upon the instar in which they assumed their typical soldier characteristics; this varies with the age of the colony. There is no worker caste, the nymphs performing this function. The nymphs and dealated reproductives (fig. 12) are approximately ½ inch long.

The winged reproductive of *Zootermopsis nevadensis* is smaller than that of *Z. angusticollis,* and is darker in color (dark chocolate-brown). Supplementary reproductives are the same color in both species. According to Castle (1934), the soldiers of *Z. nevadensis* are often confused with those of *Z. angusticollis,* but can be identified by their longer and more straight-sided head and relatively longer mandibles.

Damage to buildings in the United States from dampwood termites other than *Zootermopsis* spp. may result from occasional infestations by a species in each of two

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[5] *Z. angusticollis* is reported to be established in Louisiana (NPCA, 1966). The writer is following Harris (1961) in placing *Zootermopsis* in the family Termopsidae. It is convenient to group nearly all dampwood termites into a single family, although T. E. Snyder (correspondence) believes that on purely taxonomic grounds *Zootermopsis* should remain in the family Hodotermitidae (see Snyder, 1949).

families. The desert dampwood termite, *Paraneotermes simplicornis* (family Kalotermitidae), of the U. S. Southwest usually infests wood in moist soil at or below grade level, and sometimes girdles young citrus trees and grapevines below the soil line in desert areas.

The Florida dampwood termite, *Prorhinotermes simplex* (Hagen) (Rhinotermitidae), which inhabits the southern tip of Florida and the Caribbean area, occasionally causes some damage to buildings. Soldiers of this species are difficult to distinguish, by superficial examination, from those of *Coptotermes formosanus,* described on page 18 (Miller, 1967).

Harvester termites (Hodotermitidae)

Damage to buildings from termites is not always confined to wood structures, for there are species that can cause great destruction to buildings built of sunbaked or "green" bricks set in clay mortar. These may be hollowed out to contain the nests of harvester termites, and the walls inevitably collapse if the termites are not controlled. Even if "hard" brick is used, the termites may burrow through the mortar holding bricks together, provided it consists of lime. Harvester termites can also do considerable damage to thatched roofs or paper, cotton, and similar nonwoody cellulose goods (Coaton, 1948*b*, 1958). The most common termite pest of buildings in Lower Egypt is the termitid species *Anacanthotermes ochraceus* (Burm.). This species damages by attacking the straw in unbaked mud bricks (Kassab *et al.*, 1960).

DISTRIBUTION OF PRINCIPAL TERMITES ATTACKING BUILDINGS

The distribution of the species of termites causing major damage to buildings, arranged primarily[6] from data presented by Harris (1961) is as follows:

Rhinotermitidae

Psammotermes hybostoma Desneaux	North Africa
Heterotermes aureus (Snyder)	Deserts of southwestern U.S.A. and Mexico
Heterotermes ceylonicus (Holmgren)	Ceylon
Heterotermes convexinotatus (Snyder)	Central and South America, Caribbean
Heterotermes perfidus (Silvestri)	St. Helena
Heterotermes philippensis (Light)	Philippines, Mauritius, Madagascar
Heterotermes tenuis (Hagen)	Central and South America, Caribbean
Reticulitermes flavipes (Kollar)	Eastern North America, Europe
Reticulitermes hageni Banks	Eastern United States
Reticulitermes hesperus Banks	Western North America
Reticulitermes lucifugus (Rossi)	Europe, Middle East, North Africa, Madeira
Reticulitermes speratus (Kolbe)	Far East

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[6] The writer has added 18 species to those listed by Harris (1961) using the criterion he specified, namely, that they infest buildings regularly in at least one area severely enough to necessitate repair work. Four species (*incisus, marginipennis, minor,* and *snyderi*) were transferred from the genus *Kalotermes* to *Incisitermes* on the basis of the revision by Krishna (1961).

Reticulitermes tibialis Banks	Western United States
Reticulitermes virginicus (Banks)	Eastern United States
Coptotermes abiratus Hill	Papua and New Guinea
Coptotermes acinaciformis (Frogatt)	Australia, New Zealand
Coptermes amani (Sjöstedt)	East Africa
Coptotermes ceylonicus Holmgren	Ceylon
Coptotermes crassus Snyder	Central America
Coptotermes elisae (Desneaux)	New Guinea
Coptotermes formosanus Shiraki	Far East, Hawaii, Guam, Midway and Marshall Islands, Ceylon, South Africa, Gulf Coast of U.S.A.
Coptotermes frenchi Hill	Southeastern, southern and southwestern Australia, New Zealand
Coptotermes grandiceps Snyder	Solomon Islands
Coptotermes havilandi Holmgren	Malayan Region, Madagascar, Mauritius, Caribbean
Coptotermes michaelsoni Silvestri	Southwestern Australia
Coptotermes niger Snyder	Central America
Coptotermes pamuae Snyder	Solomon Islands
Coptotermes sjöstedti Holmgren	West Africa
Coptotermes testaceus (L.)	Caribbean, South America
Coptotermes travians (Haviland)	Malayan Region
Coptotermes truncatus (Wasmann)	Madagascar
Coptotermes vastator (Light)	Philippines, Hawaii
Prorhinotermes simplex (Hagen)	Southern Florida

Termitidae (Amitermitinae)

Microtermes diversus Silvestri	Middle East
Microcerotermes fuscotibialis Sjöstedt	West Africa

Termitidae (Macrotermitinae)

Macrotermes bellicosus (Smeathman)	Tropical Africa
Macrotermes natalensis (Haviland)	Tropical and South Africa
Odontotermes badius (Haviland)	Tropical and South Africa
Odontotermes ceylonicus (Wasmann)	Ceylon
Odontotermes feae (Wassman)	India, Burma
Odontotermes latericius (Haviland)	East, Central and South Africa, Ceylon
Odontotermes (Hypotermes) obscuriceps (Wasmann)	Ceylon
Odontotermes pauperans (Silvestri)	West Africa
Odontotermes redemanni (Wasmann)	Ceylon
Microtermes redenianus (Sjöstedt)	East Africa

Termitidae (Nasutitermitinae)

Nasutitermes ceylonicus (Holmgren)	Ceylon
Nasutitermes corniger (Motchulsky)	Central and South America
Nasutitermes costalis (Holmgren)	Trinidad, Barbados, British Guiana
Nasutitermes ephratae (Holmgren)	Central America, Caribbean
Nasutitermes exitiosus (Hill)	Southeastern, southern and southwestern Australia
Nasutitermes voeltzkowi (Wasmann)	Mauritius

Mastotermitidae

Mastotermes darwiniensis Froggatt	Tropical Australia, New Guinea

Kalotermitidae

Incisitermes incisus (Silvestri)	Venezuela, Neotropical
Incisitermes minor (Hagen)	Coastal California and peripheral desert areas of southern California and Arizona
Incisitermes snyderi (Light)	North and Central America, Caribbean
Incisitermes marginipennis (Latreille)	Central America
Cryptotermes brevis (Walker)	North, Central and South America, West and South Africa, South Atlantic, Far East, Pacific, Caribbean, Florida, Louisiana
Cryptotermes cavifrons Banks	Central America, northern Caribbean, Bahamas, Bermuda
Cryptotermes cynocephalus Light	Philippines, Malayan Region, Ceylon
Cryptotermes domesticus (Haviland)	Malayan Region, Far East, Pacific, Central America
Cryptotermes dudleyi Banks	Philippines, Malayan Region, Australia, Central and South America, Caribbean, East Africa
Cryptotermes havilandi (Sjöstedt)	West Africa, South America, Caribbean
Cryptotermes pallidus (Rambur)	Mauritius
Marginitermes hubbardi (Banks)	Deserts of southeastern California, southern Arizona, and northwestern Mexico

Termopsidae

Zootermopsis angusticollis (Hagen)	West coast of North America
Zootermopsis nevadensis (Hagen)	West coast of North America

Hodotermitidae

Hodotermes mossambicus (Hagen)	South Africa
Microhodotermes viator (Latreille)	South Africa
Anacanthotermes ochraceus (Burmeister)	Lower Egypt

Part 3. DETECTION AND INSPECTION

. . . detection
. . . inspection
. . . the standard report form

Detection

The homeowner's first warning of subterranean termites may come from seeing a flight of them. Each year, usually in fall or early winter, a certain percentage of the termite colony forms wings and emerges from subterranean galleries via emergence holes at the surface of the ground, or from "flight tubes" extending a short distance above the surface of the ground, or through cracks in the porch, terrace, patio, etc. outside the house or within basements, enclosed porches, or rooms within the house. They then start to fly away to form new colonies, but as they are not strong fliers, many of them flutter or fall around the premises from which they originated.

Flight of the more important pest species of California (*R. hesperus* and *I. minor*) occurs during daylight hours. The flight of *R. hesperus* usually begins after the first autumn rains, particularly if they are followed by warm and sunny weather. However, three or four rains may be required before sufficient moisture reaches sheltered places, to initiate the first flight. In the fall the flights of *R. hesperus* alates occur simultaneously from many colonies over a wide area. There is further emergence in the spring. In the eastern United States, flights of subterranean termites take place from March to late fall.

In southern California flights of the drywood termite, *I. minor,* occur in the fall, particularly in late September and October, sometimes in enormous swarms; in northern California, flights occur in June and July. According to Harvey (1934), optimum conditions for a flight are brilliant sunlight from a cloudless sky and temperatures from 80° to 100°F; there are practically no flights in brilliant sunlight if the temperature is below 80°F, or if there is optimum temperature and clouded sky. Few fliers emerge either before or after the main flight.

In California, most drywood termite flights occur before the first rains of late fall or early winter result in the first flights of the subterranean termites. Flight periods may, however, overlap to some extent and it behooves the observer to be able to distinguish the two species. In general the alates of the drywood termites are about ¾ inch in length—about twice the size of subterranean termite alates. Although both species are blackish in appearance, the head of the drywood termite is reddish-brown and the head of the subterranean termite is black.

If alates occur in or around a building, particularly over a period of days and in large numbers, there are probably termites in or adjacent to the structure. After a flight, or if a flight is made impossible by confinement of the termites in a structure, they cast off their wings. If cast-off wings are seen in a building, infestation of the building can be taken for granted.

Subterranean termite infestation may be indicated by blisters or darkened areas in the flooring, buckling or waviness in the floor, or by excessively cracked plaster or separated dry wall panels. Such areas may be probed with a knife or screwdriver, and if the damage has been caused by termites, only a thin readily crushed shell will be left at the surface of the infested area.

The homeowner usually becomes aware of drywood termites when he sees their fecal pellets scattered about (if they have fallen from some distance) or in conical piles if the "kick-out hole" from which they have fallen is only a short distance above (fig. 10). Subterranean termites do not produce fecal pellets. With drywood termites, however, pellets on the window sill may be to the casual observer the first sign of infestation—but sometimes the window frames collapse before the homeowner is aware of the infestation.

Fecal pellets of drywood termites somewhat resemble straw-colored to reddish-brown coarse sand, the color being influenced by the color of the wood in which they have been feeding.

Detection of termites may result from annual inspection by a termite operator. In the United States there is a trend in the direction of the "control contract" in which the pest-control operator guarantees control of termites (or termites plus other pests) for a specified fee per year. If termites (or termites plus other pests, depending on the contract) are found while the contract is in effect, it is the pest-control operator's responsibility to control the infestation without further charge. In California the seller of a property usually provides the buyer (through the escrow company) with a "termite-free clearance." This probably accounts for the majority of the termite inspections.

Inspection

Thorough inspection of the premises is always essential before control and repair work can be effectively undertaken. This is best done by a reliable, licensed termite operator. It requires much physical ability, as the inspector must crawl over dust, mud, and debris, often in spaces barely high enough to admit his body. He must crawl around the inside of the foundation, inspecting and probing wood structures and under showers, sinks, and in the vicinity of floor furnaces and fireplaces. Sometimes a minute bit of mud between two wood members, which would doubtless be missed by an inexperienced person, may be the only outward sign of an infestation.

In southern California, a complete inspection includes the examination of the attic for drywood termites. Here, the narrow spaces, the high temperatures, the dust, and the prolonged crawling over rafters make thorough inspection difficult and exhausting. Sometimes an inconspicuous bit of cottony frass outside the point where drywood termite reproductives have bored out the royal cell, usually in a crack or at the intersection of two timbers, will be the clue to a colony which might not be discovered for years through more usual signs, namely, the pellets which have fallen out of the galleries of well-developed colonies through cracks or kick-out holes.

The standard report form

A reliable inspector can provide the owner of the building with a plan of the inspected premises, indicating on the diagram the points of infestation and harzardous conditions, and an estimate of the cost of control and repair. The lowest bidder is not necessarily the most reliable operator—if his work is not thorough it may eventually prove more expensive. California has standard inspection forms, and it is compulsory to file these with the Structural Pest Control Board. Thus substandard or fraudulent operators can be detected and may then lose their licenses.

Part 4. CONTROL OF SUBTERRANEAN TERMITES

. . . destruction of the colony
. . . isolation of building from infestation
. . . preconstruction preventive measures
. . . construction of foundation and superstructure
. . . correction of environmental conditions
. . . soil treatment
. . . termite proofing of concrete
. . . procedures for specific elements of construction

Control methods employed against subterranean termites are destruction of the colony and isolation of the building from attack. The former method is generally applicable only against certain mound builders or species with reasonably accessible nests, galleries, or runways; it is seldom possible to utilize this method against species found in the U. S. The latter method is applicable against all species, and both methods can be employed simultaneously when desirable and feasible.

Destruction of the colony

Destruction of the colony is most easily accomplished by treating mounds of the mound-building species, or by injecting dusts into the shelter tubes of these and certain other subterranean termites.

Treatment of mounds

There are no mound-building termites in the U. S. In countries in which they occur they are sometimes treated by boring a hole in to the mound's central nest or "nursery region" and blowing ¼ ounce of finely powdered white arsenic or Paris green into it; the hole is then plugged to prevent the entrance of water. At little as 1.75 grams will kill an entire colony of approximately 1.5 million termites in 2 weeks (Holdaway and Hill, 1936). The same type of treatment can be used to exterminate termite nests in hollow tree trunks near buildings. Gay (1936*b*) suggests that the inside of the trunk be flooded with a dilute emulsion of aldrin, chlordane, dieldrin, or similar insecticide rather than risk killing the tree with an arsenical compound.

Both dusts and liquids have been used successfully. Das (1958) combined both methods by introducing dusts of 5 per cent DDT, BHC, aldrin, or dieldrin into the top of the mound and working them down with water. However, Deoras (1962) found that dusts of 5 per cent DDT and 5 per cent BHC, dusted into the broken towers of the mounds of *Termes malabaricus* and *Odontotermes* sp. at 2 ounces per pound, were not effective. When a 2 per cent BHC or a 2 per cent pyrethrum emulsion was poured into the towers the primary colony was destroyed, and there was no recurrence of termite damage in the vicinity.

Control methods employed in mounds may sometimes be used for the destruction of termites having their nests in the bases of trees or stumps (Casimir, 1957). E. L. Moore (correspondence) in Venezulela sprays the nests and shelter tubes of *Nasutitermes corniger* found in trees or on walls of buildings (fig. 13) with a dilute dieldrin emulsion; he has never known a treatment to fail in over 10 years.

In South Africa, arsenic-and-sulfur toxic smoke is still used; it is cheaper than benzene hexachloride toxic smoke, although both are completely effective (Coaton, 1949, and correspondence). Smokes are applied under pressure and forced through the nest system. (This treatment is

Fig. 13. Nest of a "tree termite," *Nasutitermes corniger*, on the wall of a building. Such nests are usually found in trees. Termites from this nest caused severe damage to another building 150 yards away. (Courtesy E. L. Moore.)

not used in the U.S., and would probably be considered hazardous for use around homes.)

Injection of dusts into shelter tubes

Dusting of shelter tubes and galleries has been unsuccessful against subterranean termites in the U.S.A., although dusting or otherwise treating the galleries in wood is widely practiced against drywood termites. In some areas, dusting of shelter tubes leading from ground to first wooden parts of buildings has been effective. Gay (1963*b*) states that he has obtained consistently good results with straight white arsenic (arsenic-trioxide 300-mesh screened). This method depends largely on discovery of suitable points for treatment, and on application of the insecticide *with a minimum disturbance to the termites.* Enough poison-carrying termites must return to the central nest to make this an efficient control method. Too much disturbance of a shelter tube may cause the termites to abandon it, and it is then difficult to determine whether the treatment has been successful.

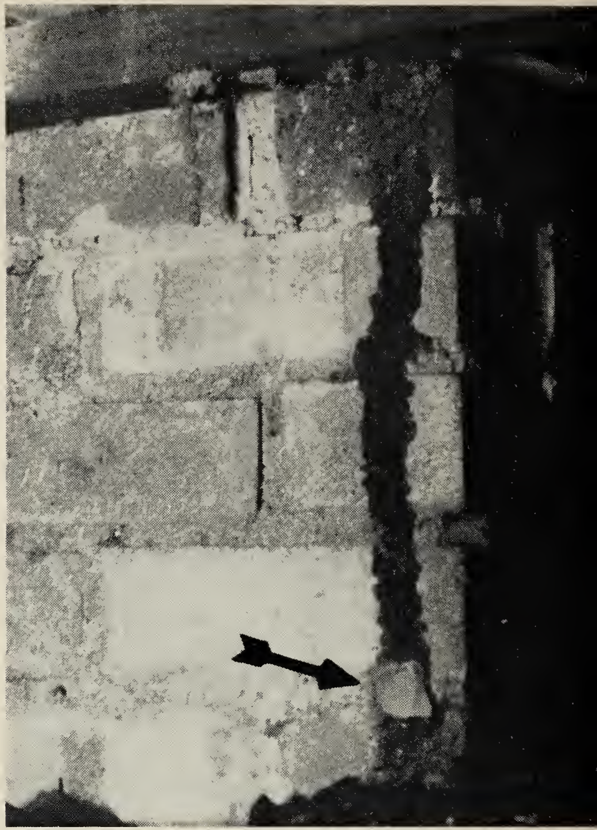

Fig. 14. Main shelter tube of *Coptotermes acinaciformis* connecting ground and floor joist. Note paper pasted over hole into which arsenic dust was blown. (From Casimir, 1957.)

Casimir (1957) states that the effectiveness of a dust depends partly on its fineness, and suggests that it should pass through a 200-mesh sieve at least. The shelter tube is carefully opened, about ⅛ ounce of the dust is blown in gently, and the hole is then sealed over (fig. 14). Treatments of wood members above tubes may be unnecessary if this is done. However, a disadvantage of dusting shelter tubes is that it provides no protection from attack by other termite colonies not using dusted tubes (Wilson, 1959).

Injection of dusts into timbers

In some areas (but not in the U.S.) arsenical dusts have been blown into infested timbers for control of subterranean termites. Casimir (1957) suggests that the opening into the galleries is best made by gently prying open infested wood, or boring a small hole into it, and sealing up any hole after dust is blown into it. Treatment should be repeated in several infested parts and treated timbers should be left undisturbed for 3 or 4 weeks; they should then be inspected and if the treatment is successful the badly damaged wood parts can be replaced.

If galleries in wood are to be treated, those running up the center of foundation piers provide the best opportunity for successful control, using inspection holes for the introduction of dust. Only a small quantity of dust should be used for galleries or tubes. Ratcliffe *et al.* (1952) state that one-fourth of an ounce is enough for 20 to 30 application points.

Limitations of control measures

The above methods are not applicable to all termite species. Randall and Doody (1934) found poison dusts effective in laboratory colonies of subterranean termites and dampwood termites as well as drywood termites, but under field conditions they were usually effective only against the latter. A direct attack on the termite colony is reasonably effective, but the destruction of a colony does not protect a structure from attack by other colonies.

Queen removal

Belief in the efficacy of queen removal as a means of destroying termite colonies is most common in Africa, Asia and Australia, where many species of termites build their nests in mounds or in other reasonably accessible locations. But even though queen removal is practiced by commercial termite exterminators (Harris, 1961), all evidence indicates that it is not effective as a control measure

Isolation of buildings

Isolation of buildings from subsequent infestations of subterranean termites is the most reliable control method ("isolation" here includes pretreatment of the soil with termiticides). Isolation, along with removal of any wood on or in the ground that might eventually become infested, is generally the only control procedure attempted. Control measures against *C. formosanus* are similar to those employed against *Reticulitermes*, always remembering that *C. formosanus* does not require as much moisture. Isolating it from the ground may not stop infestation unless all sources of moisture (such as leaking pipes and roof leaks) are dealt with.

Preconstruction preventive measures

Tree stumps and roots and wood or cellulose debris of any kind on or in the soil should be removed when the building site is graded. The ground should have sufficient slope to enable surface water to drain away from the building. Ideally, provision should be made for connecting eave gutters and downspouts to a storm sewer system. If the building is to have a basement, drainage tile around the outside is especially important.

Construction of foundation and substructure

Although no type of construction is absolutely termite-proof, much can be done at the time of construction to retard infestation, to expose termite activity, and to minimize damage and control costs. The following factors are important.

Type of foundation. Poured concrete foundations (fig. 15, A) or masonry unit foundations capped with reinforced concrete (fig. 16, B) serve to expose termite activity, for termites must build tubes over their surfaces to gain access to substructure wood (fig. 3). This is of no value, however, unless the foundation is periodically inspected inside and out.

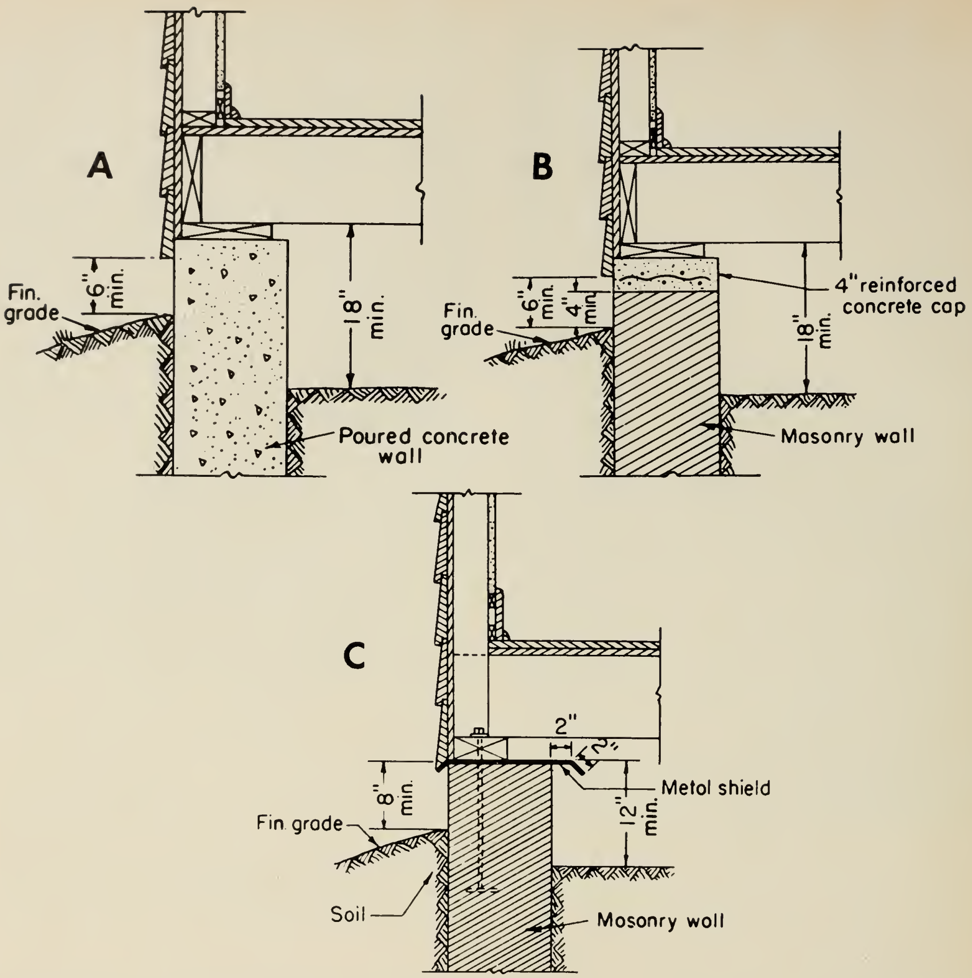

Fig. 15. Three types of foundation wall: A. poured concrete; B. masonry with a 4-inch reinforced concrete cap; C. masonry with metal termite shield. (After St. George *et al.*, 1963).

Before the foundation concrete sets, spreader sticks and grade stakes should be removed, and form boards and all lumber scraps should be removed from the site; buried wood scraps are an important source of termite infestation.

For basements, the concrete floor should be poured before wooden partitions, posts, and stair carriages are constructed, and these should never extend into or through the concrete. Concrete should be reinforced where such structures or heavy objects are to be placed. Termites can crawl through cracks only 1/32-inch wide.

Door frames or jambs should not extend into or through concrete floors. In buildings with basements it is advisable to use pressure-treated wood in window frames or other openings near or below the outside grade. The level of the bottom of the window well should be at least 6 inches below the nearest wood.

For wooden porches or steps any supports, such as piers, should be separated from the building by 2 inches to prevent hidden access by termites. Wooden steps should rest upon a concrete base or apron extending at least 6 inches above grade.

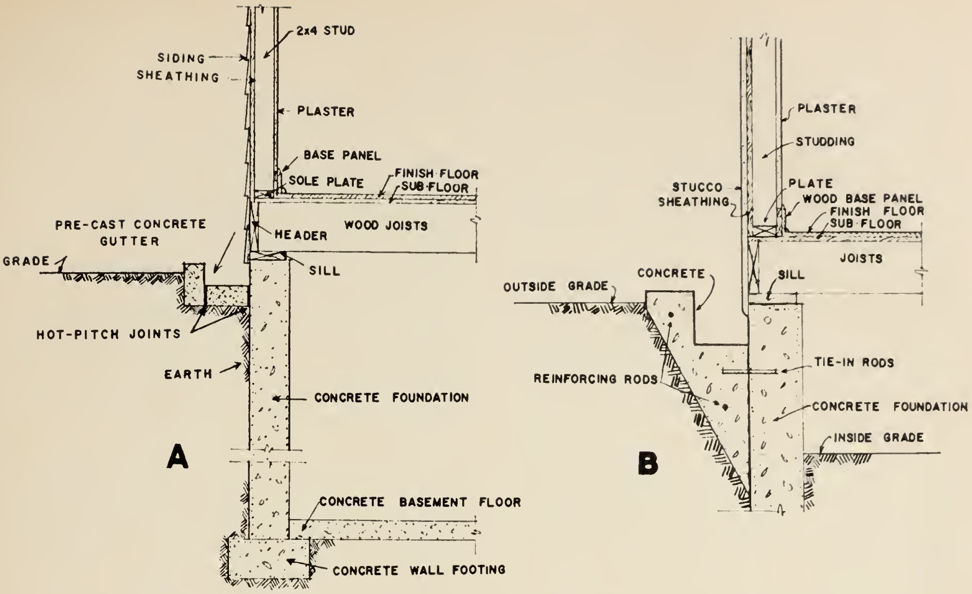

Fig. 16. Two types of gutter: A. wall and bottom of preformed slabs; B. poured concrete. (From Heal, 1951.)

Pressure-treated and naturally resistant wood for the sills

Generally, sills are of wood pressure-treated with a chemical that protects them from termite attack for the life of the building, provided that cut ends are painted or soaked with a protective solution. Termites are forced to build their tubes over pressure-treated sills just as they are forced to build them over the concrete foundation (see Lund, 1961, for photographic evidence). In addition, the sill itself is protected from damage, so the small extra cost of the chemical treatment is justified.

Chemicals used for pressure treatment of wood may be grouped into two classes: oils or oil-borne materials, and water-borne materials. When wood is subjected to leaching it is better protected by oils or oil-borne preservatives such as coal-tar creosote and its solutions, pentachlorophenol, and copper naphthenate. When the treated wood will not be in contact with ground or water, or where it may require painting, water-borne preservatives such as Celcure, Chemonite, copperized chromated zinc chloride, Wolman salt (Tanalith), zinc chloride, and zinc meta arsenite, are generally used (NPCA, 1963). Chemicals and their uses are given in (1) Federal Use Specification TT–W–571 d (current revision), (2) Standards of the American Wood Preservers Association, and (3) Standards of the National Woodwork Manufacturers' Association.

Sills also have been constructed of naturally durable or naturally resistant wood having extractives making them resistant and/or repellent to the termites. Smith (1949) believed that for timber to be resistant to termites it must also be resistant to fungi, for infection by fungi will almost certainly lead to infestation by termites if the latter are present.

In the United States, grade-marked "foundation grade" California redwood or 100 per cent heartwood of southern tidewater red cypress, or very pitchy southern pine (lightwood) or heartwood of eastern red cedar (less resistant than the above) are suggested when durable wood is required (St. George *et al.*, 1963) (but it is generally recognized that pressure-treated wood is more reliable). A brush-coat of termite- and fungus-resistant solution, while helpful for untreated sills, is not a substitute for pressure treating.

In Australia water-soluble mixtures of boric acid and sodium fluoride, with or without sodium arsenate and dichromate, are applied by dipping green lumber in concentrated solution, followed by "block-stacking" for several weeks to allow the preservative to diffuse into the timber. Lumber so treated has high resistance to *Coptotermes* even after severe leaching. (This treatment has not been used in the U.S.) Another interesting development in Australia is the use of termite-resistant composition "hardboards" containing less than 1 per cent of pentachlorophenol, arsenical compounds, aldrin or dieldrin (Gay, 1963*b*).

Termite shields. Metal shields of proper design and materials have usually been of little or no practical value, principally because they are seldom installed properly (Isherwood, 1957), but even when these are properly installed (fig. 15, C) termites may build tubes over the edge. In southern California, the consensus is that where shields are installed at earth-filled extensions of the foundation (such as porches and terraces) they are probably better justified as barriers to moisture than as barriers to termites. A far more effective barrier is a firm bond between the porch or terrace cap and the foundation, plus pretreatment with insecticide.

Metal shields tend to buckle, making it impossible to insert cement grouting to fill the void between foundation walls and undersides of sills. This results in structural weaknesses in the building, and the sharp edges of the shields can be dangerous.

Scott (1960) has called attention to the fact that shields appear to be favored nesting places for Argentine ants. He states that it is not uncommon for disintegration of the metal to take place within a few months when such nests are present, presumably because of the formic acid given off by the ants. In South Africa the undersides of the shields are often filled with carton by the termites, thus presenting no barrier to them (Coaton, 1949), and this has also been observed in the United States (Isherwood, 1957).

Clearance. Proper clearance and ventilation (fig. 16) between the ground and wood members of the substructure reduces danger from termites and decay. The Building Research Advisory Board recommends that minimum clearance between the ground and bottoms of the joists, in crawl spaces, should be 18 inches, and minimum clearance between ground and beams or girders should be 12 inches. Minimum clearance between outside finish grade and the tops of slab-on-ground foundations or tops of foundation walls in basement houses, should be 8 inches, with at least 6 inches exposed.

Correction of environmental conditions

After the building is constructed, control and prevention of subterranean termites consists, in part, of adding to, improving, or repairing the above structural features. The remainder of this section will deal with such preventive measures.

Sanitation. All cellulose-bearing debris (forms, stakes, lumber, etc.) upon which termites could develop should be removed from under and around a building.

Prevention of excess moisture. Optimum soil moisture for subterranean termites occurs when soil is continuously damp but not saturated too long. Poor drainage and inadequate ventilation are the principal contributing factors. Remedial measures may involve surface or subsurface drainage, adjustment of soil grade in relation to building substructure, correction of faulty guttering and downspouts, repair of leaky faucets, repair of stopped sewers and drains, etc.

Ventilators built into the foundation wall should have openings that allow movement of air while keeping out small animals. Screens of sufficiently small mesh to keep out winged termites would be too small to admit air freely, at least after becoming clogged with spider webs and debris. The California Minimum Standards specifies ¼ inch hardware cloth. Shrubbery should not be allowed to interfere with free passage of air into the ventilators.

In the United States, the National Pest Control Association (NPCA) specifies in its Approved Reference Procedures (ARP) that, for average conditions, "structures with a perimeter of 200 feet or less should have a minimum of 2 square feet of ventilation for each 25 lineal feet of outside foundation. For structures of a perimeter of 250 feet or more, ventilator openings should be provided with an area of 1½ square foot for each 25 lineal feet of exterior foundation wall plus ½ of 1 per cent of the area enclosed in the foundation. For structures between 200 and 250 feet of perimeter either formula may be used." (Heal, 1951)

If drainage and ventilation do not reduce soil moisture sufficiently it is helpful to cover exposed soil with heavy roofing paper. A "vapor barrier" usually consisting of a sheet of some synthetic material impervious to water, may be placed on the ground previous to the pouring of the concrete in slab construction. The type of soil under a house is an important factor affecting the moisture arising from subsurface water. Thus, a gravel substrate provides a uniform structural base and breaks capillarity. Low humidity helps to keep the under-area dry, but in arid regions this advantage is often nullified by excessive and careless irrigation of vegetation around the foundation. In areas of high humidity sufficient moisture may be present in various parts of the building to maintain colonies of subterranean termites without connection with the soil. Localized areas of excessive moisture in the superstructure may develop in any climate from leaf-filled gutters or water traps on flat roofs, leaky shower pans, overflowing drip pans under ice boxes, slow leaks in plumbing, or condensation from cold water pipes.

Membrane barrier on foundation. The membrane barrier is a facing of flexible sheet material sealing the outside of the foundation against termites; it serves the same purpose with respect to termites that membrane water-proofing serves for moisture. In the United States, the barrier usually consists of a tarred felt paper attached by means of hard tar pitch onto a foundation free of soil and reasonably dry. A priming coat of tar paint is brushed or sprayed on before the melted pitch and tarred felt paper are applied. Neither asphalt derived from petroleum nor natural asphalt is used as the binding material, for they have little resistance to termites.

Lowering the grade. When it is not practical to raise the building to provide at least 18 inches of clearance between the soil and the lowest horizontal wood members of the substructure, the inside grade should be lowered by excavation. Sometimes only "crawling ditches" are provided to allow inspection and chemical treatment. However, lowering of the inside grade and digging of ditches is undesirable in high water-table areas if this results in excessive dampness or standing water.

Gutters. When wood sills on foundation walls are at or below grade, a gutter may be required to lower soil or grade level to below the sill. The bottom of the gutter should be at least 4 inches below the sill. Gutters are usually made of preformed concrete slabs or poured concrete—figure 16, A is an example of the former. Preformed slabs are used as a retaining wall and as the bottom of the gutter. Joints should be properly filled with hot pitch, and the gutter should be at least 8 inches wide to allow easy removal of debris. Figure 16, B shows a poured concrete gutter.

Raising of foundations. Where stucco construction is widely used, the foundation is sometimes raised to bring the sills at least 6 inches above grade. Usually a few lineal feet of the substructure is removed at a time, the new foundation is built up to the desired height, and the new substructure is built upon it. However, in certain sections of the country it is com-

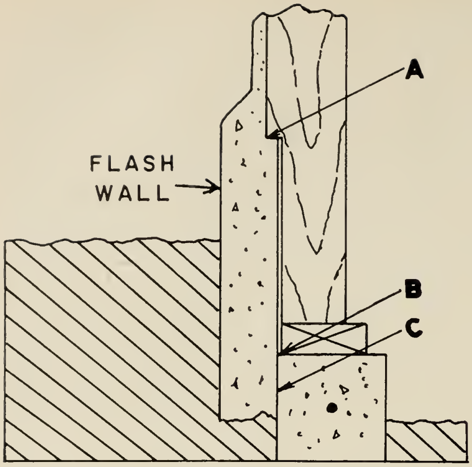

Fig. 17. Conventional flash wall, showing points of weakness. Water may leak down wall or enter through stucco at A and collect at B, where it may be responsible for termite or fungus problems. At C there is a "cold joint" which may provide access for moisture or for termites.

mon practice to support the entire structure and raise the entire foundation at one time. (The term "raise" is somewhat misleading—the foundation is not really raised, but is increased in height).

Flash walls. The flash wall (fig. 17) is a solid poured-concrete facing, firmly bonded to the foundation and, according to the Minimum Standards Code of the California Pest Control Operators, it must extend at least 4 inches below the top of the foundation and a minimum of 3 inches above natural grade level. It must be a minimum of 3 inches thick, and the top must be sloped to provide adequate drainage away from the walls of the house.

The flash wall is used as a relatively inexpensive alternative to raising the foundation when the latter procedure would normally be indicated—as when the sill is below the top of an adjacent concrete slab, or below the earth grade. It is most justified when raising the foundation would be excessively expensive (as when the floor joists rest on the sill). Flash walls have often proved unsatisfactory because water may enter from above and the flash wall is apt to become loose from the foundation, thus providing hidden access for termites.

"Sealing off" earth-filled extensions of foundation. Concrete porches, terraces, patios, and steps are often supported on an earth fill. Such earth fills frequently harbor subterranean termites, usually because carpenters leave wood debris in these areas. The consensus of termite operators in California is that most subterranean termite infestations originate in earth-filled extensions of the foundation.

Although the earth is originally sealed away from the concrete foundation and the wood members it supports, this seal may be broken by earthquakes, sonic booms, gradual subsidence of the earth, or by extremely cold weather—and termites then have access to the wood. To remedy this, termite operators in California usually break out a strip of the floor of the porch, terrace, etc. adjacent to the building and excavate the earth fill down to the top of the footing of the foundation.[7] The soil adjoining the seal is always drenched with a suitable liquid insecticide and reinfestation in the treated area is unlikely. The exposed portion of the foundation and the cut edge of the floor are then well cleaned and concrete is poured into the excavated area (fig. 18). This is a common and very basic operation in California and is called the "seal-off."

An ornamental wall adjacent to a porch slab (lower left, fig. 18) is common in California but the sill in this wall is vulnerable to termite infestation. Mechanical alteration consists of removing a section of slab along the wall and sealing the earth away from the foundation with concrete, as described above. However, the soil is first treated with liquid insecticide and cracks, if any, in the foundation wall are flushed with toxicant and sealed.

Tunnelling earth-filled extensions of

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[7] A straight cut about ¼ inch deep is made in the concrete approximately 8 to 10 inches from the building, using a carborundum blade in a portable circular saw; the concrete can then be broken to a straight edge. When the excavation is filled, a joint is made with a jointer along the straight edges cut by the carborundum blade and the finished porch retains a neat appearance.

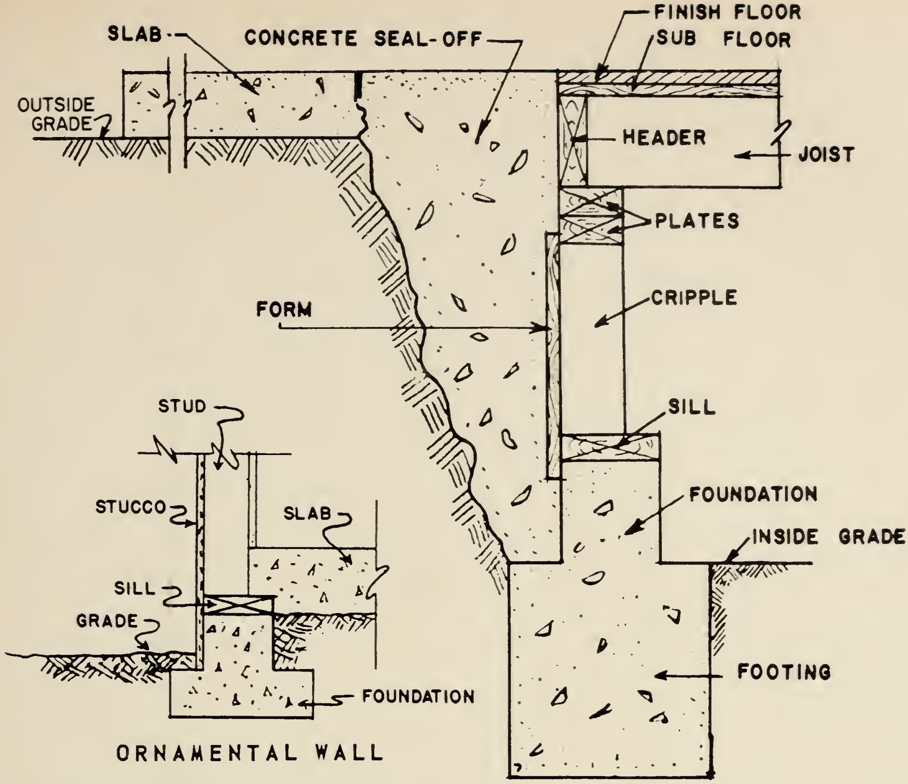

Fig. 18. Concrete "seal-off" used to seal foundation away from earth-filled porch. Lower left: ornamental wall sometimes built around a slab porch; this may also require a sealoff. (From Heal,1951.)

foundation. Tunnels for inspection and treatment should lower the earth fill to at least 4 inches below the lowest point of potential contact with structural wood adjacent to the tunnelled area. Normally this is 4 inches below the top of the foundation wall, but when brick walls rest on a footing the clearance should be down to 4 inches below the top of the footing.

The general earth level usually has receded a few inches from beneath the slab at time of tunnelling, and shelter tubes can generally be seen crisscrossing in all directions in the thin layer of earth adhering to the underside of the slab. Some termite operators emphasize the importance of spraying the underside of the slab, from the tunnel, with a suitable insecticide and with considerable pressure.

Treating foundation with toxicant. Because even tiny cracks in concrete foundations can be penetrated by termites, cracks should be flushed with insecticide liquid and sealed off mechanically, using a rich cement mortar with a minimum of water, or melted coal-tar pitch. With brick foundations, the mortar between bricks or the bricks themselves are drilled and the voids between brick layers are flushed out with insecticide liquid. Usually only one space between the header layers is treated all the way around the foundation.

The problem of void flooding presents itself with other types of foundation, such as concrete block, hollow tile, veneer, and stone and rubble, each demanding somewhat specialized procedures that have evolved from the accumulated experience of the termite-control industry.

Treating wood substructure with pentachlorophenol emulsion. Pentachlorophenol, C_6Cl_5OH, is one of the principal toxicants used for pretreatment of timber used for construction, telephone poles, railway ties, fence posts, etc. "Mayonnaise-type" oil emulsions containing 10 per cent pentachlorophenol and widely known as "Woodtreat-TC" have long been used for applying a maximum quantity of termiticide and fungicide on subfloor wood members not pretreated before construction. Nowadays "Woodtreat-TC" also contains 0.5 per cent technical heptachlor (0.36 per cent actual heptachlor).

Using a paintbrush or a specially designed "caulking gun," mayonnaise-type emulsions can be applied in a thick layer containing about 20 times more toxicant than can be applied with a single brush coat with an unemulsified oil solution. As the emulsion breaks, the toxic solution is gradually released to penetrate into the wood. Termites have a tendency to burrow as closely to the surface as is possible without causing the infested wood member to collapse. Therefore the penetration of toxicant to the galleries is quite likely. Woodtreat can be applied to such wood members as mudsills or floor plates on concrete, either for prevention of infestation by termites or to get rid of an existing infestation. It is particularly effective when applied generously where two wood members come together, as at the intersection of a girder, joist, or cripple on a mudsill, or a stud on a floor plate.

Chemical-resistant gloves and a mask designed to remove organic vapors should be worn by the operator during application of pentachlorophenol emulsion. If skin is accidentally contaminated, the material should be removed by soap and water.

Soil treatment

One of the most important means of isolating a building from termites is the insecticide-treated soil barrier. Soil treatment is most effectively done before and during construction of the foundation. It is of particular importance when concrete slab-on-grade construction is used.

Recommended insecticides. At the U. S. Forest Service's Southern Forest Experiment Station at Gulfport, Mississippi, boards were laid on or wood stakes driven into treated soil, in forested land heavily infested with the eastern subterranean termite, *Reticulitermes flavipes.* Aldrin, chlordane, dieldrin, and heptachlor have given complete protection against subterranean termite attack for periods from 14 to 18 years, depending on when the material was applied (Johnston, 1960). Concentrations recommended are 0.5 per cent for aldrin, dieldrin, or heptachlor, and 1.0 per cent for chlordane.

Benzene hexachloride (BHC) at a concentration of 0.8 per cent of the gamma isomer (lindane) was 100 per cent effective for only 8 years, but heavy rainfall (approximately 80 inches annually) in the test area may have adversely affected lindane, which is soluble in water to the extent of 10 ppm. The initial toxicity of lindane to termites is extremely high (Ebeling and Pence, 1958) and it is often used in southern California in attempts to exterminate termites under slab. Lindane is relatively volatile but as Bess *et al.* (1966) have pointed out, when the objective is to create an effective barrier throughout the area immediately underneath a concrete slab, volatility could be beneficial even though the more volatile insecticides are generally the least persistent.

Among the materials that have now passed the Forest Service's 5-year test are dry granular formulations of certain chlorinated hydrocarbons (Beal and Smith, 1965). Beal and Smith applied the following quanities of granules per 10 square feet of soil surface in their plots in the same pine-hardwood forest of southern Mississippi where the tests with liquid formulations are located: aldrin 0.5 pound, benzene hexachloride 0.9 pound, chlordane 1.0 pound, dieldrin 0.5 pound, and heptachlor 0.5 pound. The resulting deposits of toxicant were equivalent to those obtained from liquid formulations at the concentrations and dosages which are currently being recommended.

It is not known whether granular formulations will provide protection as long as emulsions, which have been tested for as long as 18 years. Also, no data are available to show how effective the granules would be when applied on top of coarse fill material, in layers in perimeter treatments, or in the voids of hollow blocks. Beal and Smith believe that until granular formulations are known to be effective for such purposes, emulsions should continue to be used. Long-term soil-treatment experiments (begun in 1947) for which statistically significant data are now available are being made in Australia. Wood stakes are used in these studies, mostly around the mounds of subterranean termites. Termite species involved are *Nasutitermes exitiosus, Coptotermes lacteus, C. acinaciformis, C. frenchi, Heterotermes ferox,* and *Microcerotermes* sp. On the basis of results to date, the Australians are recommending aldrin, dieldrin, or lindane at 0.5 per cent and chlordane at 1 per cent (Gay, 1963*a*).

Globules of insecticide emulsions are largely strained out by the first half-inch of soil, but lindane was found to be uniformly effective in the first 1½ inches of soil (Ebeling and Pence, 1958). A petroleum carrier causes an insecticide to retain a uniform degree of effectiveness as deeply as the solution penetrates, but is often unsatisfactory because of its tendency to "creep up" on foundation walls and penetrate concrete slab. Oil solutions should not be used under concrete slabs unless a membrane barrier impervious to both oil and water vapor separates treated soil from the slab. Oil solutions are also a fire hazard while they are being applied.

Methods are available for checking thoroughness of soil treatment, as well as dosage of toxicant. Dyes consisting of metallic oxides will form fine suspensions in a dilute emulsion and impart various colors (red, green, etc.) depending on the metal, to the treated soil (Berzai, 1964), thus clearly marking the treated areas. For chemical analysis of soils sprayed with aldrin or chlordane, a soil-test kit has been devised, based on the research of Chisholm *et al.* (1962). Soil extracts are applied to chromatographic paper and resulting color variations are compared with those resulting from standard concentrations supplied in the kit (Anonymous, 1964). A relatively simple bioassay technique, using *Drosophila melanogaster* as the test insect, was developed by Coleman (1966) and used successfully to determine the concentration of the commonly used chlorinated hydrocarbon insecticides in treated soils taken from under buildings.

Some compounds not generally used in the U.S.A. are: BHC and lindane, because of the lingering odor of the former and the insufficient longevity of both (according to Forest Service tests); pentachlorophenol and sodium arsenite, because of lack of sufficiently prolonged residual effectiveness and (in the case of the latter) because of possible injury to humans, pets, and ornamental plants. DDT may be used at 8.0 per cent concentration, but it has sufficiently prolonged residual effectiveness as a soil insecticide only when formulated in an oil base, and this severely limits its usefulness. For vertical injection through concrete slab, ethylene dibromide gas has been known to exterminate a colony 15 feet from the point of injection but has also failed to reach termites only 1 foot away from the point of injection. (Ethylene dibromide is a dangerous fumigant, and should be used only by experienced pest-control operators.)

Field experiments made with experimental concrete slabs showed that ethylene dibromide gas moves readily under slabs in coarse gravel, but is greatly restricted in clay soils with fine particles. A high content of organic matter also restricts the movement of the gas, as in peat or muck soils. Moisture content of the soil is another important factor. Osmun (1958) concludes that no prediction of results can be made unless much is known about the above factors at the time of treatment and that in any case fumigation is not a panacea in the control of termites under slabs. The hazard to the occupants from subslab EDB injection must also be considered—a fumigant *can* find its way into the heating system beneath the slab and from there into the house. (Osmun, 1958)

Dosages and application methods. Dilute water emulsions, or dilute solutions in base oil (deodorized kerosene) of aldrin, dieldrin, and heptachlor are recommended at 0.5 per cent and of chlordane at 1.0 per cent concentration (NPCA 1965*a*). A gallon of emulsifiable concentrate (E.C.) of the above insecticides in formulations recommended for soil treatment for termites, contains the following quantities of toxicants: aldrin, 4 pounds; chlordane, 8 pounds; dieldrin, 1.5 pounds; and heptachlor, 4 pounds. (These insecticides are seldom used in base oil for pretreatment of soil for termites—see page 41.) To obtain the recommended percentages in dilute water emulsions, the above insecticide formulations should be added to water in the following proportions: aldrin, chlordane, and heptachlor, 1 gallon of E.C. per 99 gallons of water, and 1 gallon of dieldrin per 36 gallons of water.

In applying insecticide to broad areas, only enough pressure is required to break the liquid into a spray so that it can be evenly distributed; for application along foundation walls, the liquid need not be broken into a spray.

To treat slab-on-ground: apply 1 gallon of the diluted insecticide emulsion to 10 square feet as an over-all treatment under slab and attached porches. Over-all treatments applied to washed and ungraded gravel fills or fills of an absorbent material (*e.g.* cinders) should be increased by ½ gallon per 10 square feet. Apply 2 gallons per 5 linear feet to critical areas under the slab, such as along the inside of foundation walls and around utility entrances and interior partition foundation walls. Apply 2 gallons per 5 linear feet along the outside of the foundation.

To treat crawl-space houses and basement houses: For treatment made at the time of construction (pretreatment) generally not all the crawl space is sprayed. Two gallons of the spray liquid is applied per 5 linear feet to the inside of foundation walls and around piers and utility entrances. However, sometimes termites eventually build shelter tubes from the ground up to the nearest timber. Sprays can then be applied to the entire subfloor area, as well as to the inside of the foundation walls. The entire crawl space is also generally sprayed if termites have been found in scraps of wood on the ground, even though the wood is removed.

Along the outside of foundation walls (including the part opposite entrance platforms, porches, etc.) apply 2 gallons per 5 linear feet where the foundation is deep. Apply 1 gallon per 10 square feet of soil surface as an over-all treatment only where the attached porches, entrance platforms, utility entrances, etc. have covering slabs on fill or ground.

To treat voids of unit masonry walls: treat all voids of unit masonry walls and piers, using 1 gallon per 5 linear feet applied from grade to footing.

Application techniques for pre- and post-treatments. In slab-on-grade construction an over-all treatment should be applied to the ground or fill on which the concrete is to be poured. Unless treated ground or fill is to be promptly covered with a vapor barrier or by the slab, precautions must be taken to prevent disturbance of the treatment and human or animal contact with the treated surface. To avoid surface flow of the toxicant from the application site, treatments should not be made when the soil or fill is excessively wet, or immediately after heavy rains.

Applications should be made so as to provide a barrier of treated soil immediately adjacent to the wall or pier, from grade to footing. Probably the most common method is to dig a trench along the foundation wall and sprinkle a dilute insecticide emulsion into it; the trench is then refilled with soil and more liquid is applied to treat the backfilled soil. Trench depth depends on the depth to which the liquid must penetrate to reach the footing of the foundation, and on the nature and condition of the soil. Liquid can also be applied to a shallow trench around the foundation as a supplement to rodding, as discussed below.

When pre-treating for either slab-on-grade or joist-type construction remember that areas such as earth-filled extensions of foundations or, in the case of slab, the areas surrounding utility pipes, are particularly important avenues for the entry of termites and should be given special attention.

If the termite operator wishes to modify the recommendations of such agencies as the NPCA and FHA he should, in the writer's opinion, confine this modification to the volume of the carrier per unit area of soil, rather than the quantity of insecticide. It seems reasonable to use half the recommended volume of water when treating damp soil and twice the recommended concentration of insecticide, thus applying the same amount of insecticide per unit area. When treating unusually dry, porous, or sandy soils, doubling the quantity of water, and halving the concentration of insecticide, is a reasonable modification of standard procedure. When a liquid's distribution cannot be seen (as in subslab injection) a decrease in concentration with a corresponding increase in gallonage of liquid is particularly appropriate.

A survey of nearly 100 termite operators in the U.S. revealed that when treating under slab 55 per cent of them drilled downward through the slab, 31 per cent preferred horizontal rodding, and 14 per cent used both methods. Sixty-nine per cent used 100 psi of pressure or less for injecting insecticide liquids (Anonymous, 1961).

For vertical injection, proximity of the holes to one another should depend on the nature of the earth or fill below the slab. If the slab is underlaid with heavy soil, 3 feet between holes might be appropriate; if underlaid by sand fill or gravel, 6 feet apart may be adequate. A sound procedure is to drill holes about 6 feet apart and see if the liquid is forced out of nearby holes. If not, more holes can be drilled until there are enough to provide a reasonably complete coverage of the subslab area.

Because of the hazard of drilling through pipes, conduits, plumbing, or the possibility of destroying a vapor barrier and the expense and hazard in removing tile, parque, etc., many termite operators treat from the outside by drilling through the foundation wall.

Horizontal subslab rodding involves drilling holes through the foundation at a height allowing entry immediately below the usual 4-inch cap of the slab (fig. 19). Figure 19, A, shows a 22-foot iron pipe being inserted into one of these holes. The pipe was pushed in to a distance of 20 feet with a back-and-forth motion while insecticide was flowing at 4 to 5 gallons per minute. A neoprene cone or stopper over the pipe prevents a premature backflow of the liquid (fig. 19, B and C).

Figure 19, C, shows that the liquid has spread laterally for a distance of 6 feet; Spitz (1958) believes that the lateral spread is uniformly greater than 3 feet as the pipe is being pushed in, and that the grid pattern formed by pushing the pipe in from all sides of the foundation results in soil saturation. He uses from 800 to 1200 gallons of liquid per 1000 square feet of slab area, and injects about 1½ times the amount of insecticide that would be applied in a pretreat job (for which the rate of application is usually 100 gallons of the dilute spray to 1000 square feet). In this operation the outside perimeter of the foundation is also treated and as much liquid is put into the bath trap (inspection area under the bath tub) as it will hold.

Marshall (1966) discussed the advantages and disadvantages of vertical drilling of slab, short rodding, and long rodding. He prefers vertical drilling, but points out that holes must be drilled more than 4 inches away from the foundation wall so that the inserted rod will miss the foot of the foundation. Short rodding is a less expensive method than vertical drilling. A short rod, through which the insecticide solution is forced under the slab, is placed in holes drilled through the foundation from the outside. These holes should not be drilled so low that a layer of untreated soil, next to the slab and expansion joints,

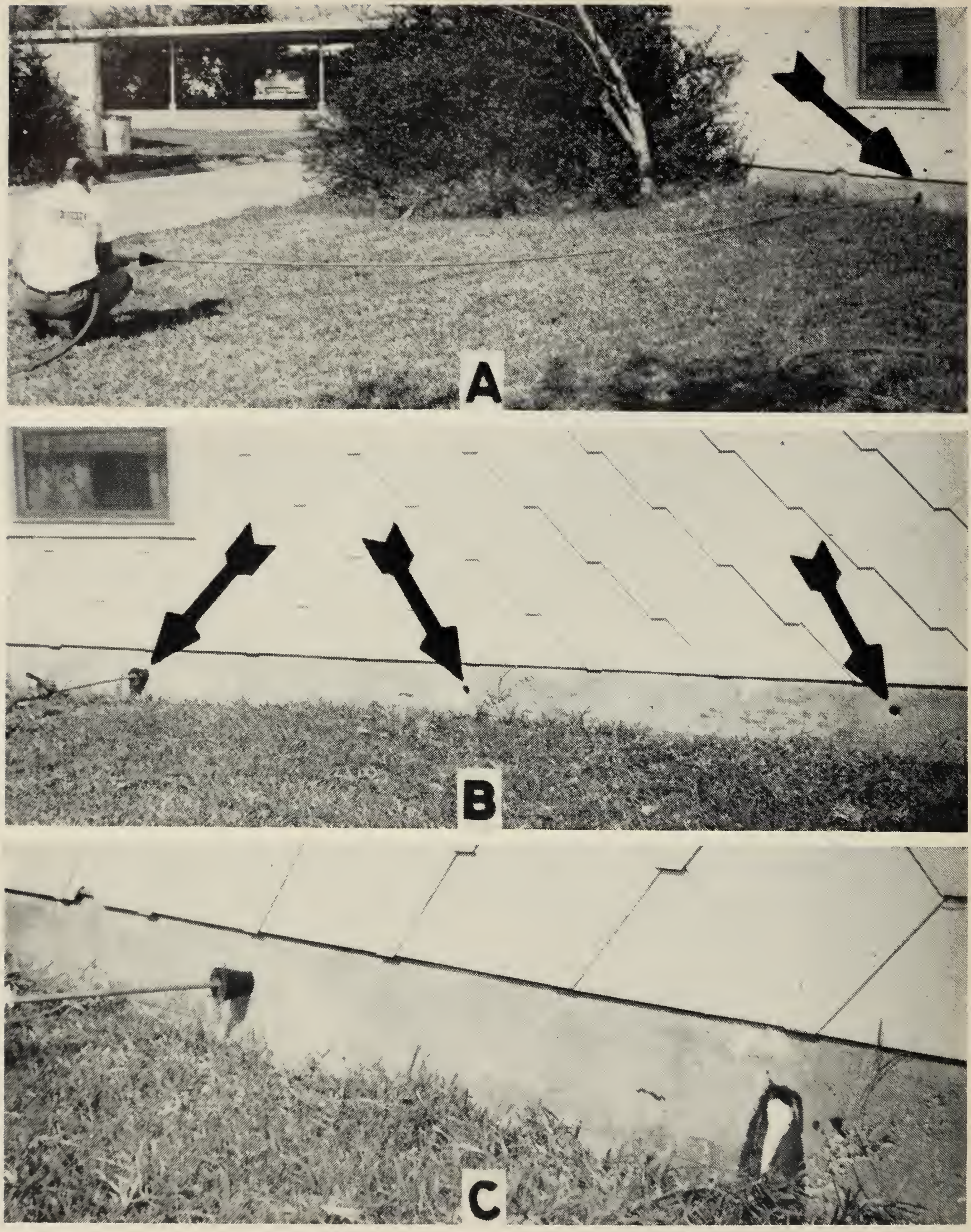

Fig. 19. Horizontal rodding of slab-on-grade foundation. A. 22-foot iron pipe at the moment of entry into a 1⅛-inch hole in foundation (arrow). B. pipe after being pushed to nearly its entire length under the slab floor, and two more holes (arrows) drilled 6 feet apart. C. two holes in the slab foundation, one (left) filled with the neoprene cone that fits over the pipe and plugs the hole to prevent backflow. Hole at right, with liquid flowing out, shows that the liquid can spread laterally for a distance of 6 feet. (From Spitz, 1958.)

may be left above the treated portion. Long rodding is the least expensive method. At each corner of the building a hole is drilled on each face of the corner of the foundation and a long rod is forced through each hole parallel with the foundation, more than halfway to the opposite wall. The insecticide then injected provides a complete chemical barrier along the inside of the foundation wall beneath the slab. The remainder of the slab must be examined, and treated if necessary by vertical rodding. Rodding does not eliminate the need for exterior trenching, and treating voids in concrete block walls or spaces between bricks and concrete blocks.

In subslab treatment there is the possibility of drilling into various pipes or ducts, and the problem is aggravated by the fact that blueprints are unreliable as a guide to drilling. Penetration of heat ducts can be avoided by using a depth gauge on the drill (Marshall, 1966). Pescop (1965) says that if the heating system is turned on to full and damp cloths or towels are laid along the wall to be drilled, heat pipes beneath the floor will dry out the cloths and outline the pipes' position (colored towels are preferred because color differences between a dry colored towel and a wet colored towel are greater than with white towels). The method is effective on concrete floors with rubber or asphalt tile, but it will not reveal piping beneath parquet wood tile.

The efficacy of insecticides which are not uniformly distributed depends to a great extent on their movement in the soil after treatment. Brook (1965) made experiments in Vaiden clay loam soil in Mississippi in which holes 1 inch in diameter and 4 inches deep were spaced 6, 8, and 12 inches apart in small plots. Insecticides were poured into the holes as per standard recommendation for trench treatment, but water was reduced from the usual 2 gallons per 5 square feet to 1 to 2 quarts per square foot. Two months later sufficient insecticide had moved through the soil so that rod samples resulted in termite (*Reticulitermes flavipes*) mortality from an 18-hour exposure. With hole spacings increased to 16, 20, and 24 inches, bioassays 6 weeks after treatment and some rainfall showed that dieldrin had migrated more than had chlordane. Termites placed on soil cores from all three spacings of dieldrin-treated plots were moribund or dead in 24 hours, while those from chlordane-treated plots had 90 to 100 per cent alive in soil taken from the 24-inch spacings and 70 per cent alive from the 16- and 20-inch spacings.

Brook (1965) also treated small field plots with aldrin, dieldrin and heptachlor at 0.25, 0.5, and 1 per cent concentrations and chlordane at 0.5, 1 and 2 per cent concentrations, applied as soil drenches. Parts of the plots were covered, the remainder being left exposed to the weather. Nearly 2 years after treatment, bioassays showed that all four treatments resulted in 80 to 100 per cent of the insects being moribund in 24 hours. Approximately the same results were obtained from covered and uncovered parts of the plots.

CAUTION

All insecticides used for the prevention and control of termites are toxic to man. Labels on insecticide containers should be carefully read and heeded. All insecticide containers should be clearly labelled, and stored where children and pets cannot get at them. Protective equipment, such as chemical-resistant gloves, goggles, and respirators, should be used. Poisons can be absorbed through the skin, and therefore contaminated parts of the body should be washed thoroughly with soap and water.

Repeated daily exposure to these compounds may result in a chronic poisoning that can become serious without preliminary warning. Therefore it is vital to rigidly observe all safety rules.

Termite-proofing concrete

Adding long-lasting toxicants to concrete foundations can deter subterranean termites, and is often useful even where soil treatment is made. Gay and Wetherly (1959) substituted a 0.5 per cent emulsion of dieldrin for the normal mixing water to prepare a termite-proof concrete. They found that workers of *Nasutitermes exitiosus* and *Coptotermes lacteus* confined in cylinders of treated concrete were affected after 2 hours of contact and that complete mortality occurred in 24 hours; exposure of 1 hour was sufficient for complete mortality. They also found that while the termites could make their way through a "no fines" concrete containing only coarse aggregates, this type of concrete treated with dieldrin was not penetrated. Gay (correspondence) states that laboratory tests have shown aldrin to be as effective as dieldrin when used in the same way and at the same concentration. Strength of the concrete was not adversely affected by the treatment, and accelerated weathering procedures did not destroy its insecticidal effectiveness.

Allen *et al.* (1961) added a 75 per cent dieldrin wettable powder to water used in concrete so that concentrations of the toxicant in cement blocks were approximately 0.1 and 1.6 per cent by weight. A week later the insecticide in these blocks resulted in a 100 per cent mortality for *Reticulitermes flavipes* workers having contact with them for 1 minute, and for *Nasutitermes columbicus* nasutes exposed 10 minutes. Allen *et al.* (1964) found that after 16 months the newly cracked surfaces of laboratory-aged mixtures were equivalent in toxicity to the original surface of new mixtures.

Procedures for specific elements of construction—joist-type

In this section, alteration and control procedures will be related to termite problems occurring in common elements of joist-type or conventional construction, as classified and defined in *The Approved Reference Procedures* of the National Pest Control Association (Heal, 1951). Procedures discussed for each element will be (1) mechanical alteration, (2) soil treatment, (3) foundation treatment, and (4) wood treatment. In joist-type construction, regardless of what specific problems arise with regard to soil treatment around the foundation, soil under the house may also be treated to prevent the swarming of winged reproductives in places where there may be wood stumps, roots, etc., below the surface, using water emulsions of insecticides at the recommended concentrations and dosages as discussed on page 42. Some of the construction discussed in this section is unsound, from the standpoint of susceptibility to termite infestation, and would no longer meet the more stringent specifications of modern building codes. It is for this reason, as well as for the fact that such construction is found in older buildings, that it is of specific interest in connection with termite control.

Sheathing of stucco-frame house in contact with soil

Figure 20, A, represents a cross section through the foundation and substructure of a stucco-frame house with stucco and the underlying sheathing extending below the top of the foundation and contacting the soil. The short studs extending from the mudsill or foundation sill up to the floor joists are commonly referred to as "cripples." This is an old type of construction in California and because it is old the incidence of termite infestation is high.

Most of the following procedures pertain to this type of construction with wood siding, except when (as often occurs in old houses) the siding extends below grade and is in contact with soil. The lower siding board may then be removed and a flash wall or metal strip installed in its place.

Mechanical alteration. One of the following procedures may be used:

Raise the foundation according to methods previously described (*i.e.*, parts of the sheathing, stucco and cripples are cut off a section at a time at a suitable point above the sill, and the foundation is built up to this point with new pressure-treated sills).

Excavate soil to a point below the stucco and sheathing and install a concrete gutter.

Remove stucco and sheathing to a point not lower than the top of the sill and install a flash wall (page 38).

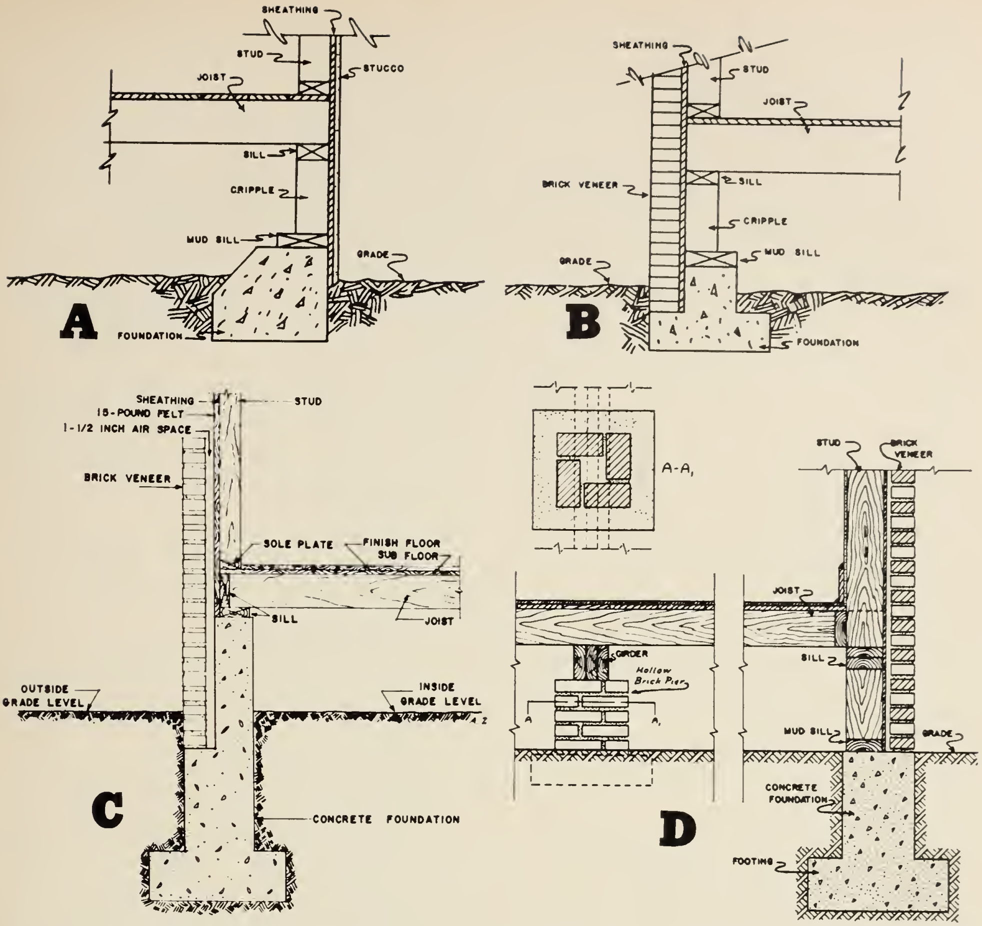

Fig. 20. Types of construction: A. sheathing of stucco-frame house in contact with soil; B. brick veneer construction with wood sheathing extending below soil line; C. brick veneer extending below grade on frame house; D. sill at grade on frame house, brick veneer, hollow brick intermediate pier. (From Heal, 1951.)

Drill from the inside so that the sheathing can be pulled out below the sill and the resulting void filled with cement grout.

Soil treatment. Treat soil from grade to footing, inside and outside of the foundation (page 42).

Foundation treatment. If there are cracks in the poured concrete foundation they should be flushed with emulsions of aldrin, chlordane, dieldrin or heptachlor and sealed.

Wood treatment. Newly installed wood members such as sills or cripples should be pressure-treated wood. All points of juncture between sill and foundation, and between sills, cripples and sheathing, should be flushed with liquid insecticide.

Brick-veneer construction with wood sheathing extending below soil line

The type of construction shown in figure 20, B, is common in California and it sometimes is found in other parts of the U.S. Basic similarities can be seen in the types of construction shown in figure 20, A, and 20, B. In the latter, the principal difficulty is that subterranean termites may enter the sheathing by penetrating the mortar joints of the brick veneer below grade, even though the wood sheathing is not in direct contact with the soil.

Mechanical alteration. Any one of the following forms of mechanical alteration may be used:

Remove veneer bricks a section at a time from the foundation to above grade. Remove sheathing up to this point and replace bricks and sheathing with solid concrete; or replace the bricks, using cement mortar and fill the void formed by the removal of the sheathing with cement mortar.

Install a flash wall or a concrete gutter, with the bottom of the gutter at least 2 inches below the lowest course of brick veneer.

Soil treatment. Trench and treat the soil from grade to footing, inside and outside the foundation.

Foundation treatment. If there are cracks in the foundation, they should be flushed with liquid insecticide and sealed. All junctures between sill and foundation, and between sills, cripples and sheathing, should be flushed with a liquid insecticide.

Wood treatment. Flush points of juncture between sill and foundation, and between sills, cripples, and sheathing, with a liquid insecticide.

Brick veneer extending below grade on frame house

Figure 20, C, represents the cross section of a frame building veneered with brick, with poured-concrete foundation wall and several courses of brick below grade. This type of foundation will usually develop cracks within a few years. As in the type of construction represented by figure 20, B, an important avenue of infestation is through the mortar joints below grade in the brick-veneer wall on the outside.

Mechanical alteration. Any one of the following may be used:

Remove lower course of bricks to above grade line. Remove all rubble and fill void with concrete. Replace brick, using cement mortar. A short section of approximately 2 feet should be removed and replaced at a time.

Lower grade on outside to not less than four inches below the lowest layer of brick, using a retaining wall or gutter.

Install a flash wall or membrane barrier on the foundation (pages 37, 38).

Soil treatment. This supplements mechanical alteration, and is important only when the latter is not practical. Soil is trenched and treated from grade to footing of foundation, inside and out.

Foundation treatment. If there has been no mechanical alteration the void between veneer and foundation should be flushed with insecticide.

Wood treatment. The sill, header, and cracks between them and floor joists, as well as any cracks between the box sill and the foundation, should be flushed with liquid insecticide.

Sill at grade on frame house, brick veneer; hollow brick intermediate pier

Figure 20, D, represents a cross section of a frame house with brick veneer facing resting on a poured concrete foundation, the top of which is flush with grade line. The sill rests directly on foundation at grade line. Studs resting on this sill support another sill on which the floor joists rest. The brick pier carrying the weight of the center of the house is hollow. The proximity of the sill to soil and the hollow construction of the pier are serious termite hazards.

Mechanical alteration. Lower grade level both inside and outside foundation at least 4 inches. Install a gutter or a membrane barrier inside and outside foundation.

Soil treatment. Thoroughly treat soil inside and outside foundation unless grade has been lowered or a membrane shield installed, in which case a light application would suffice. The soil around the hollow brick pier should also be treated.

Foundation treatment. Drill the wall void from inside or outside and flush with a toxicant. Drill into the pier void and flood with a toxicant.

Wood treatment. Flush wood joints above pier and foundation with a toxicant. Drill the three-piece girder above the pier

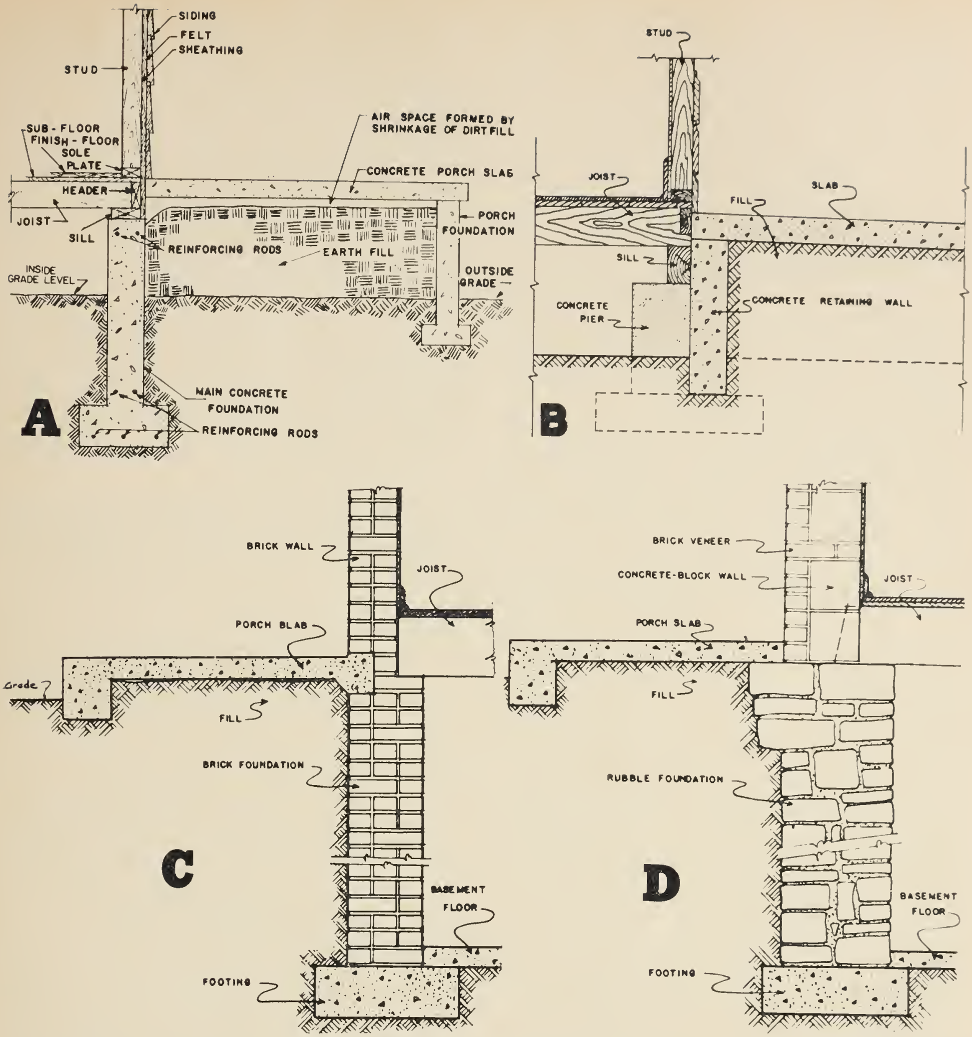

Fig. 21. Types of construction: A. earth-filled concrete porch on frame house; B. earth-filled porch with concrete retaining walls against concrete piers of frame house; C. slab on fill against brick foundation, brick house; D. slab on fill against rubble foundation, concrete-block wall, brick veneer. (From Heal, 1951.)

from both sides and flush between joints with a liquid insecticide.

Earth-filled concrete porch on frame house

Figure 21, A, represents the cross section of a frame house with an earth-filled concrete porch and a concrete foundation wall, the latter having reinforcing rods to reduce the possibility of cracks. Here the sheathing is close to or in contact with the soil and thus may be an access for termites. Earth-filled porches are serious termite hazards throughout the U.S., and in southern California are thought to be—along with other earth-filled foundation extensions—the source of over half the infestations in houses.

Mechanical alteration. A space can be excavated along the foundation under the slab so that sills and other wood members can be inspected. Adequate drainage and ventilation of the porch area should be provided; if the bottom of the tunnel is below grade, a retaining wall can be built around the entrance to keep out water.

The seal-off can be used if there is evidence of a crack at the cold joint between the foundation and the porch slab.

For concrete-block construction with earth-filled porch, treatments are similar to those above. Because foundation blocks have four voids, however, there should be a tunnel under the porch slab so that the outside row of voids can be treated.

Soil treatment. Trench and treat soil on the inside of foundation to provide chemical barrier from footing to grade; if the porch has been excavated as described above, the remaining soil in the trench (as well as the accessible soil under the slab) should be chemically treated.

If the porch is not excavated, or if a seal-off has not been installed, the entire area under the porch should be treated with a dilute insecticide emulsion using either vertical or horizontal grouting rods (pages 42 to 45).

Foundation treatment. Cracks occurring in the poured-concrete foundation should be chemically treated and sealed.

Wood treatment. The sill, header, cracks between them and floor joists, cracks between sill and foundation, and any accessible termite-infested wood members, should be flushed with liquid insecticide. Exposed sheathing should be chemically treated.

Earth-filled porch with concrete retaining walls against concrete piers of frame house

Figure 21, B, is a cross section through an earth-filled porch covered with a concrete slab and attached to a frame house supported by solid wooden sills resting on concrete piers. With this type of construction if there is a good bond between the retaining wall adjacent to the house and the poured concrete floor of the porch, there is no access for termites from under the porch to the wood members of the house. However, there is seldom a firm bond between the retaining wall of the porch and the supporting pier of the house, and therefore the juncture often provides access to termites.

Mechanical alteration. Cut away retaining wall adjacent to house on each side of the pier to a minimum of 4 inches above inside grade, thus providing a clearing on both sides of the pier so that soil may be treated.

If the bond between the retaining wall and the floor of the porch is not firm, or if there are cracks in the retaining wall, or if termites gain access to wood members of the house, the porch should be tunneled or a seal-off installed.

Soil treatment. Treat soil thoroughly around the pier, and particularly in the clearing provided on each side of the pier by the above alteration.

Foundation treatment. None is indicated unless there are cracks in the foundation piers, in which case cracks should be flushed with liquid insecticide and sealed.

Wood treatment. Flush joints above the foundation pier with liquid insecticide, with particular attention to the juncture between foundation sill and retaining wall.

Slab on fill against brick foundation

Figure 21, C, represents a brick building with a brick foundation with two layers of brick in the building proper and three in the foundation. The floor joists rest on the foundation. Most likely avenues of infestation are from the soil under the porch up through voids in the brick foundation to ends of floor joists.

Mechanical alteration. The porch may be excavated to provide room for inspection, but a serious water problem might be created because of the low terrace.

Soil treatment. Whether or not the slab is tunneled, treat soil under the slab with sufficient liquid insecticide to create a barrier down to the footing. If there is evidence of infestation, the floor of the basement may be drilled and treated with liquid insecticide.

Foundation treatment. If soil has been removed from under the slab, drill through the mortar joints of the foundation to the void between the outside and middle courses of brick, and fill this void with liquid insecticide. Similarly, drill and treat voids which can be reached from inside the foundation. If the slab of the terrace has not been tunneled, drill to both rows of voids in the foundation from the inside.

Wood treatment. Flush ends of floor joists, and junctures between the joists and the top of the foundation, with liquid insecticide.

Slab on fill against rubble foundation, concrete-block wall, brick veneer

Figure 21, D, represents a hollow-concrete-block house, veneered with brick, and with a tie-in course of brick above each two rows of blocks. The foundation is of rubble stone (field stone) set on the poured concrete footing. Floor joists rest directly on the foundation and are set in between the concrete blocks. The porch is of poured slab, only slightly above grade. The irregular voids in the foundation mortar joints are the usual avenues of access to subterranean termites; hidden ends of the floor joists make inspection difficult.

Mechanical alteration. As with the above (fig. 21, C) tunneling under the porch slab to provide room for observation is desirable, but may create serious water problems. If there is damage to the ends of floor joists, they may be cut off while the main joists are shored up and replaced with pressure-treated wood, using a double-spliced joint—or joists may be permanently shored up and the ends not replaced.

Soil treatment. Treat the soil under the slab with sufficient liquid insecticide to assure an adequate chemical barrier down to the footing of the foundation. If there is evidence of infestation, the basement floor can be drilled so that soil beneath can be treated with the insecticide.

Foundation treatment. It may sometimes be desirable to drill down at any angle from the inside, starting as near the top as possible and going down to a point short of the foundation. The drill holes may then be repeatedly filled with insecticide and the liquid allowed to seep through the mortar. If mortar is soft it may be necessary to apply new mortar to the inside of the foundation and drill through the face-coating; insecticide can then spread through the old mortar.

Wood treatment. Unless the ends of the floor joists have been cut off they should be well flushed with liquid insecticide. If the liquid cannot reach the ends along the sides of the joists, the latter may be drilled at an angle down from the sides to the ends.

Brick foundation and brick basement floor

Figure 22, A, represents a cross section of a frame house on a two-course brick foundation with a solid foundation sill. The footing and the basement floor are likewise of brick. This is for the most part an old type of construction. Considerable termite hazard results from the proximity of the sill to the soil. Likewise termite swarmers may arise from the brick floor because the bricks are usually laid without any kind of bond between them.

Mechanical alteration. Under some conditions, such as when it is desired to block access of termites without the use of insecticide treatment, a membrane barrier (page 37) may be required.

Soil treatment. Trench and treat the soil outside the foundation. It may sometimes be necessary to temporarily remove a row of bricks from the floor of the basement along the footing and apply a soil treatment. If termites are under the basement and the bricks do not have a tight bond between them, flood the floor with a liquid insecticide. Cellulose material should be kept off the floor.

Foundation treatment. Drill mortar joints at a point above grade level, flood wall voids with a liquid insecticide and then fill the drill holes.

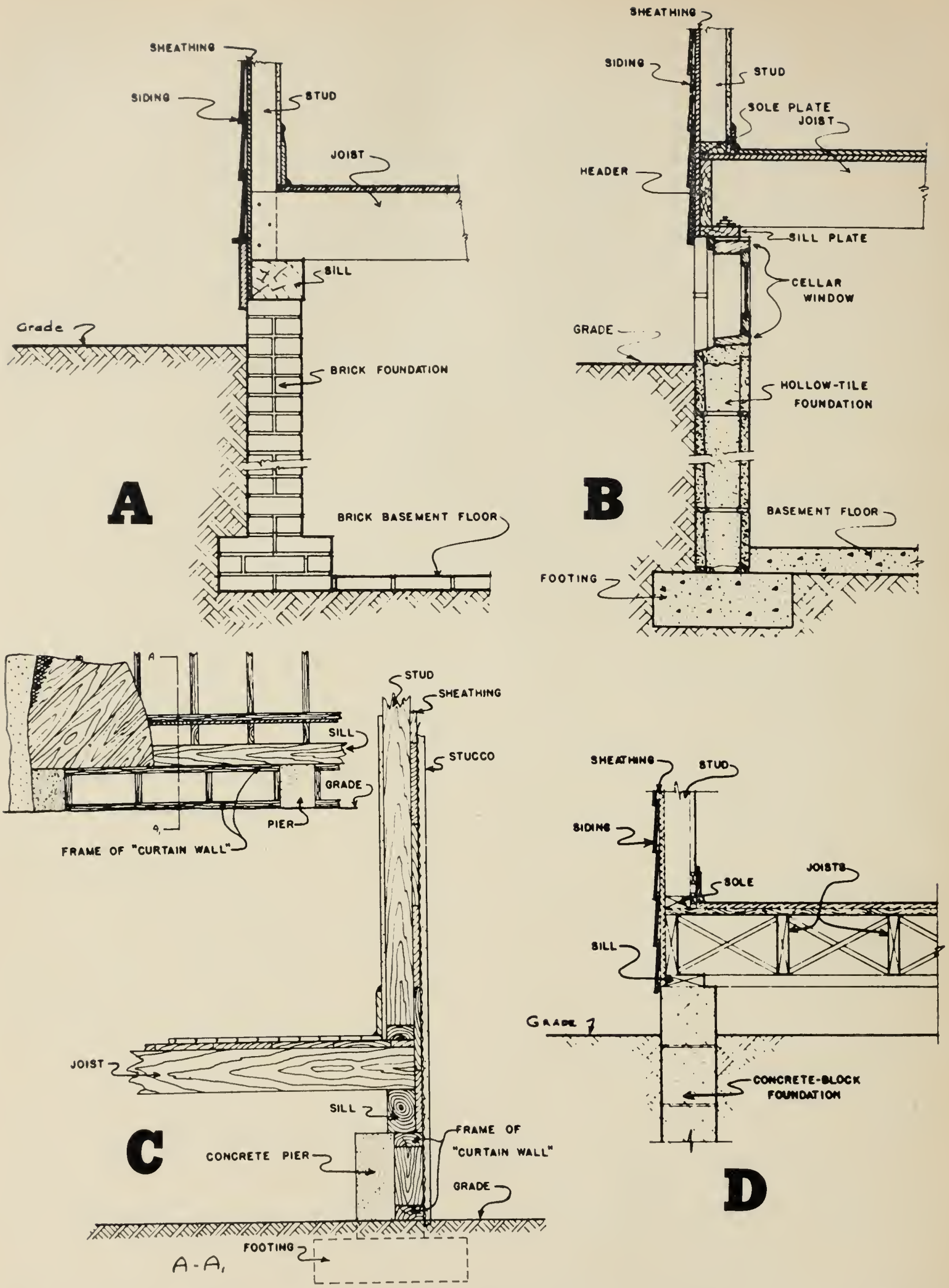

Fig. 22. Types of construction: A. brick foundation and brick basement floor; B. concrete-block foundation with cellar window; C. wood framing between concrete piers supporting stucco-frame building; D. sills close to grade on unexcavated house. (From Heal, 1951.)

Wood treatment. Flush all juncture points between wood members or wood and masonry with a liquid insecticide.

Concrete-block foundation with cellar window

Figure 22, B, is a cross section of a hollow-concrete-block foundation at a cellar window. The wooden frame of the window is set in concrete, which seals the voids in the top row of blocks but does not always make them impervious to termites. If there is no window, termites may travel through the hollow blocks to the sill plate.

Mechanical alteration. Proximity of the wood window frame to earth makes it vulnerable to subterranean termites. If such a problem exists, a shallow concrete window well or areaway may be installed, or the wooden frame may be replaced with a steel frame.

Soil treatment. Trench and treat soil outside the foundation from grade to footing. Drill the basement floor close to foundation wall and apply a liquid insecticide under pressure.

Foundation treatment. Drill mortar joints so as to enter each void in one row of blocks at a convenient height above grade. Apply liquid insecticide and seal drill holes.

Wood treatment. Apply a liquid insecticide into all spaces entirely around window frame, using a wedge if necessary to pry open a crack sufficiently large for flushing. If this is not practical, a series of small holes may be drilled through the window frame to the foundation frame and the liquid flushed in under pressure.

Spray or brush on a liquid insecticide to all accessible infested wood in the window frame or above the window and above the wall at all points of contact of wood on wood or wood on concrete.

Wood framing between concrete piers supporting stucco-frame building

Figure 22, C, represents a cross section of a frame house, veneered with stucco and supported by poured concrete piers resting on poured concrete footings. A "curtain wall" or skirting extends from the foundation sills down to the grade line between the concrete piers. Termite hazard is serious unless provision is made for adequate drainage and ventilation, and some means provided to keep the lower horizontal member of the curtain wall or skirting frame from touching soil.

Mechanical alteration. Cut off the studs of curtain wall or skirting frame high enough to prevent soil contact. Remove the lower frame members from soil; stucco facing need not be removed.

Soil treatment. Treat soil along inside of stucco between and around piers.

Foundation treatment. Flush and seal cracks in concrete piers.

Wood treatment. Treat outside sills with insecticide.

Sills close to grade on unexcavated house

Figure 22, D, represents a cross section of an unexcavated or basementless house with sills close to grade. The foundation wall is of hollow concrete blocks. This type of construction is conducive to termite infestation.

Mechanical alteration. One of the following alterations should be made:

Excavate soil from under the entire house to provide a minimum of 18 inches of clearance under floor joists.

If excavation is not feasible make access by cutting trap doors through the floor, or cut entrance wells through the foundation. Provide sufficient tunneling for close inspection, and adequate access for proper treatment. Removed soil should be brought out from under the house. If excessive moisture is a factor, provide adequate ventilation.

Soil treatment. Trench and treat soil from grade to footing, inside and outside the foundation.

Foundation treatment. Drill foundation blocks and treat voids in them with liquid insecticide. Drilling may be done from the outside when the trench dug for soil-treating is open. If treated from the inside some voids may be flooded, as the sill may not cover all voids. There is some danger of electrical shock when electric drills and other power tools are used under buildings in damp soil.

Wood treatment. Flush sill and header, and the cracks between them and the floor

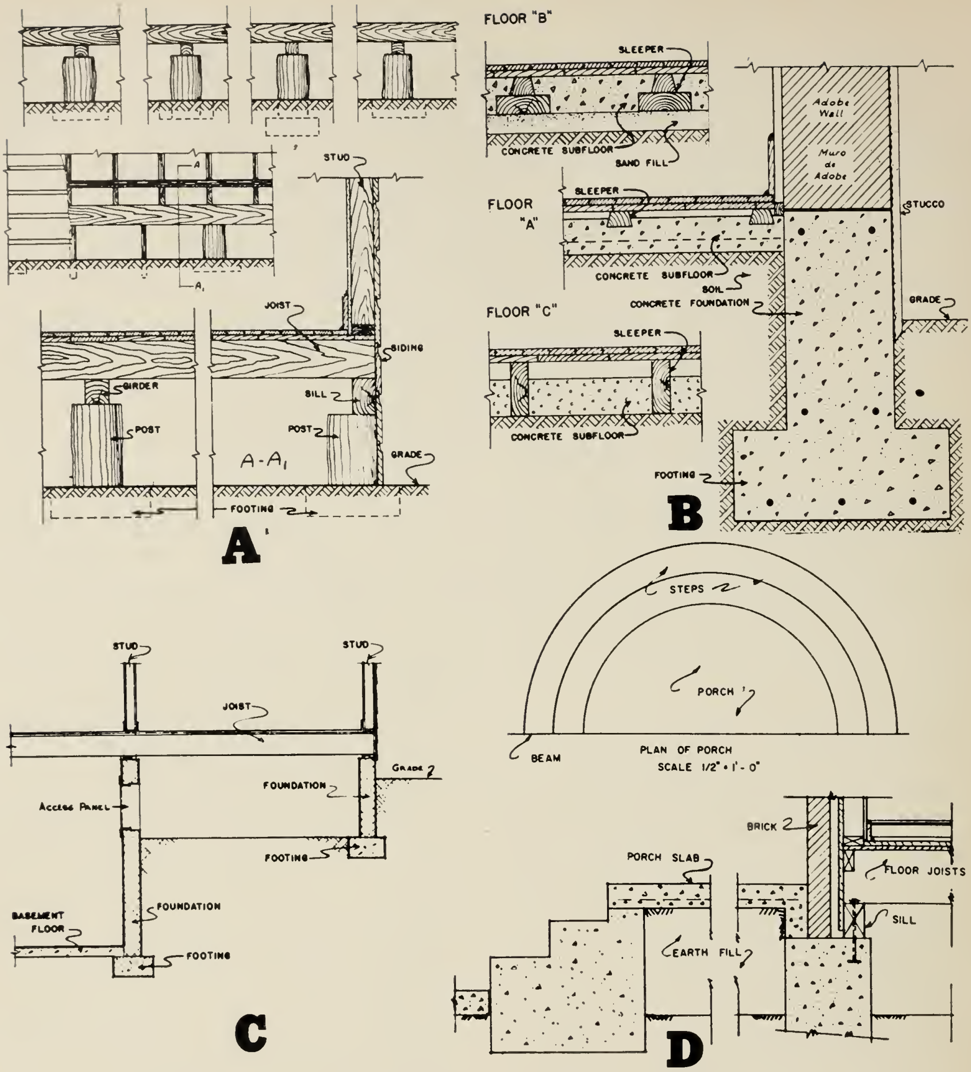

Fig. 23. Types of construction: A. frame building on wooden posts; B. adobe wall house with wooden floors on sleepers in concrete; C. partially excavated sun porch; D. semicircular earth-filled concrete porch on frame house, brick veneer. (From Heal, 1951.)

joists, as well as any cracks between the sill and the foundation, with liquid insecticide.

Frame building on wooden posts

Figure 23, A, represents a cross section of a frame house with a foundation sill resting on wooden posts or piers, which in turn rest on concrete footings. The shiplap siding occurs all the way down to the grade line. This type of construction presents a serious termite hazard.

Mechanical alteration. One of the following procedures may be used:

Replace all wooden piers with poured concrete or other termite-proof material. Cut off siding and the studs backing it at a minimum of 4 inches above the soil, and fill the intervening space with some termite-proof sheet material, making adequate provision for ventilation.

If for economic reasons the above procedure cannot be followed, remove soil from pier footings, drill holes diagonally down through the posts to the center of the bottom of the post, and flush these holes repeatedly with a liquid insecticide. Cut off studs and remove them from soil. It is also desirable to remove the lowest siding board.

Soil treatment. Treat soil thoroughly around piers, whether old ones have been left in place or new ones installed. Treat soil under skirting whether or not it is removed from contact with the soil.

Foundation treatment. See second paragraph under "*Mechanical alteration*" above.

Wood treatment. Flush wooden joists above piers with a liquid insecticide.

Adobe-wall house with wooden floors on sleepers in concrete

Figure 23, B, represents a cross section of an adobe-wall house, with steel-reinforced concrete foundation and footing, and a wood floor laid on sleepers (screeds, stringers), which in turn are imbedded in a concrete subfloor. The adobe wall has stucco on the outside and plaster on the inside. Figure 23, B, shows three possible floor constructions, the one designated as A being attached to the building. Subterranean termites often penetrate adobe and work their way into window or door frames.

Mechanical alteration. If window and door frames are infested they should be removed and a concave cup made in the adobe wall surrounding the frame. This cup should then be filled with concrete and the frames replaced.

Remove stucco and its backing to at least 4 inches above grade and replace it with concrete, bonded directly to the concrete foundation.

Remove wood floors, sleepers, baseboards, and the small wood strip under the inside plaster wall and replace with concrete or other termite-proof material.

Soil treatment. If the above procedures are not economically justifiable, treat soil outside the foundation from grade to footing, and use a membrane barrier or treated backfill (replaced soil) to protect the lower edge of stucco and prevent termites from entering the adobe wall through the space between foundation and stucco.

With all three types of floors shown in figure 23, B, drill all the way through the concrete subfloor via the sleepers in B and C and treat soil under the subfloor. For A it may be satisfactory under some circumstances to flood only the space between the subfloor and the floor. With C there is no reason for not drilling all the way to the soil, because of the ease of penetrating the entire distance via the sleepers. In B there is no space to flood between subfloor and floor, and it is necessary to drill all the way through to the sand fill and treat it with liquid insecticide. In all cases, properly fitted dowel plugs should be used to close drilled holes.

Foundation treatment. Cracks found in the foundation after stucco is removed should be filled with liquid insecticide.

Wood treatment. If old window frames are put back into place, spray all surfaces that will contact the wall with two coats of liquid insecticide. Use pressure-treated wood for any replacements. If floor and baseboard are not replaced, loosen the latter and flush with a liquid insecticide between it and the plaster wall.

Partially excavated sun porch

Figure 23, C, is a cross section of a house with a basement and an attached sun porch which has been only partially excavated or, in some cases, entirely unexcavated. Access should be made to the area under the sun porch, but there is some danger of thereby causing an odor problem in the basement.

Mechanical alteration. Cut an access hole through foundation wall between basement and sun porch and fit a removable frame into it—this can be readily inspected periodically. If porch is entirely unexcavated, excavate it at least partially to provide adequate clearance between soil and joists. Provide adequate ventilation if excessive moisture is present

Soil treatment. Treat soil inside and outside the foundation on all sides of the sun porch.

Semicircular earth-filled concrete porch on frame house, brick veneer

Figure 23, D, represents a cross section of a semicircular porch and step, with an earth fill. The porch slab may be faced with tile or other materials hard to replace. The junction between the porch and the foundation may provide hidden access for subterranean termites.

Mechanical alteration. If the porch floor is of ordinary concrete, remove a strip of concrete and excavate earth fill next to the house. Then either install a seal-off, or treat the soil and leave a tunnel under the porch with a trap door for access. If the floor is of valuable tile, the sealing off and drilling and flooding with insecticide may be difficult to do without causing excessive damage. However, it may be possible to open the foundation wall beneath the pan and remove the earth fill from the porch. A louver or panel should be installed in the opening to facilitate future inspection.

If none of the above procedures is practicable, shore up floor joists permanently and remove sill and some of the sheathing to a short distance beyond the end of the porch, thus denying termites access to wood members. The bond between the ends of the steps and the house should be checked and repaired if necessary.

Soil treatment. The fill under the porch may be flooded with liquid insecticide through a hole drilled through porch floor. Soil on the inside of the foundation should be trenched and treated.

Foundation treatment. Drill through sheathing between the ends of floor joists and flood the space between sill and the brick veneer with a liquid insecticide.

Wood treatment. Flush all accessible joints between the sill and foundation, and between the sill, sheathing and floor joists, with a liquid insecticide.

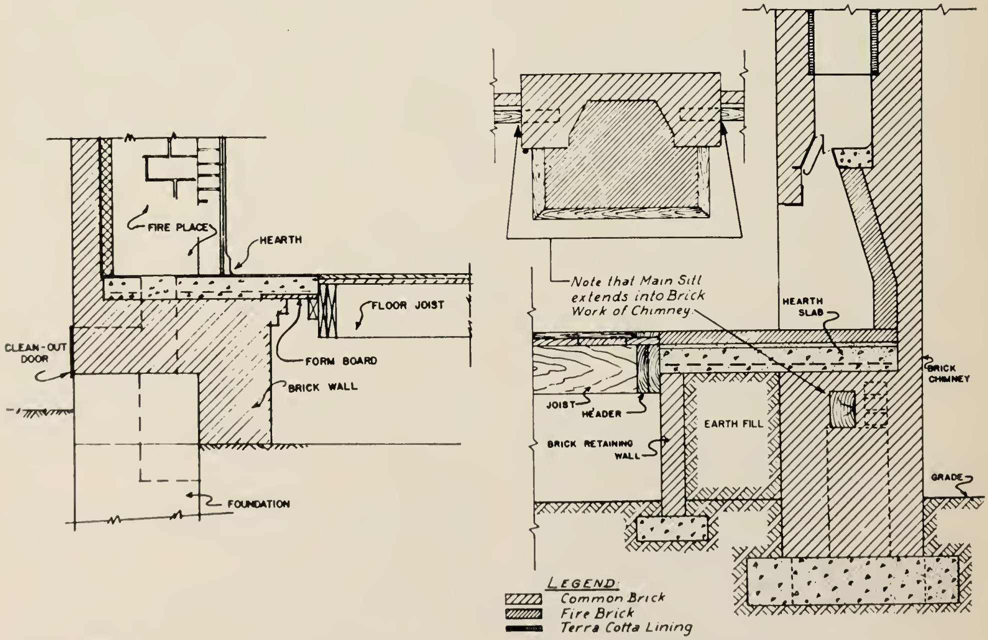

Fig. 24. Types of construction. Left, fireplace of unexcavated house; right, earth-filled fireplace of unexcavated house. (From Heal, 1951.)

Fireplace of unexcavated house

Figure 24, left, is a cross section through a fireplace with a clean-out door outside the house. The brick fireplace is set into a poured concrete foundation (some are earth-filled, and this should be checked before treatment is begun). There is a hearth form board between the fireplace and the header at the end of the floor joist; this is installed so that concrete can be poured for that part of the concrete hearth extending beyond the bricks.

Termite problems result because of the poor bond often found between the concrete foundation and the brick fireplace, and because the form board under poured concrete hearth is liable to infestation by termites entering from inside the foundation of the fireplace, whether the latter is earth-filled or not.

Mechanical alteration. Remove form board under the inner edge of the hearth. If there is an earth fill, remove it if practical. If there is a weak bond between foundation and fireplace, treat cracks with liquid insecticide and then seal them.

Soil treatment. Treat soil all around fireplace, and inside also, even if an earth fill has been removed.

Foundation treatment. If there are two or more layers of bricks in the foundation, drill them to determine if voids exist between the courses. Flood voids with liquid insecticide. If the bond between foundation and fireplace has been opened or drilled it should be thoroughly flooded with the liquid.

Wood treatment. Flush all junctures between the header and the ends of the floor joists adjoining the hearth.

Earth-filled fireplace of unexcavated house

Figure 24, right, is a cross section of the type of fireplace often found in houses without basements. The house foundation sill extends into the brickwork of the chimney. A header course at the end of the floor joist is fitted firmly against the subfloor of the fireplace. An earth fill under the subfloor of the fireplace brings soil well above the inside and outside grade line. Termite problems derive mostly from the main sill extending into the fireplace, and the easy access for termites between the earth fill and the header which contacts the subfloor of the fireplace.

Mechanical alteration. Remove earth fill and cover the hole thus made with a flanged metal door. Cut off main sill close to fireplace and remove the end extending into fireplace.

Soil treatment. Trench and treat soil to the footing of all walls.

Foundation treatment. Drill and flush voids in chimney base.

Wood treatment. Drill and flush fireplace header and any joints between fireplace and surrounding wood members.

Procedures for specific elements of construction— slab-on-grade

Concrete slab-on-grade foundations, both for homes and commercial buildings, are now widely used. This type of construction requires special alteration and control procedures for subterranean termites.

Three types of concrete slab-on-grade construction

Figure 25, A, represents a cross section of monolithic concrete slab-on-ground construction, in which the floor (cap) and footing are poured in one continuous operation so that there are no cold joints which might eventually form cracks and allow access for subterranean termites. However, other avenues of termite entry (such as cracks in the floor, or apertures around utility pipes) are as common as with other types of slab-on-grade construction.

Figure 25, B, shows a "suspended slab" extending completely across the top of the foundation. The foundation and the floor are constructed as independent units. Even though a vertical crack may develop in the foundation this type of construction prevents enlargement of the crack.

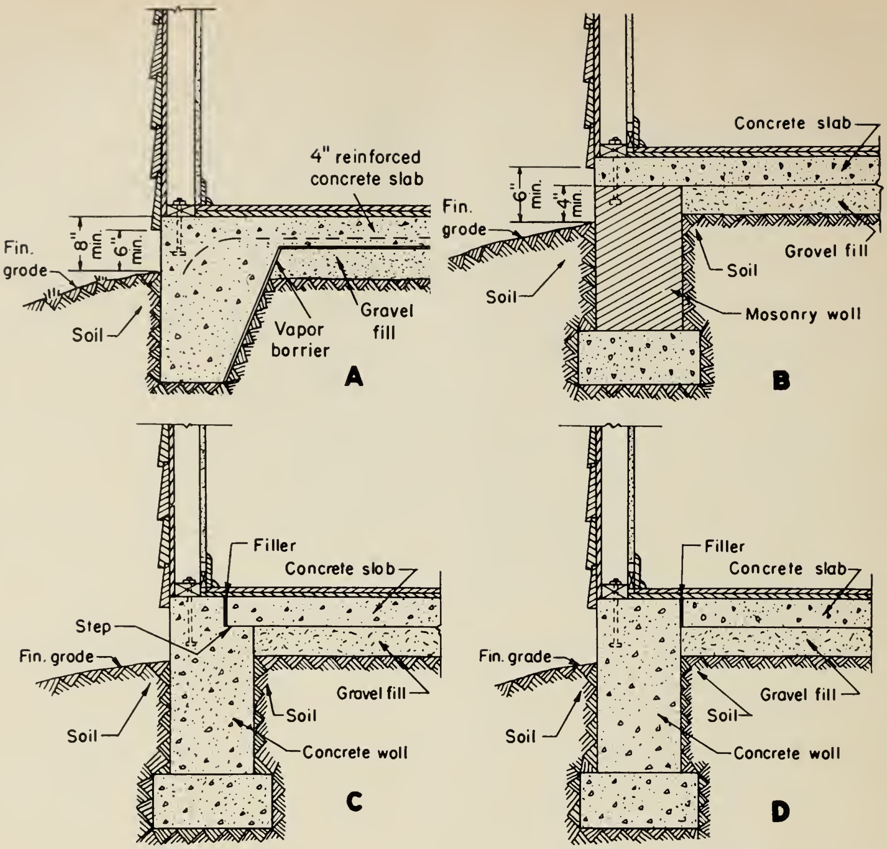

Fig. 25. Slab-on-ground construction. A. monolithic; B. suspended slab; C, D. floating slab type of construction in which slab rests on a ledge of the foundation (C) or is independent of it (D). (From St. George *et al.*, 1963.) The "filler" in the expansion joints in C and D usually consists of a roofing grade coal-tar pitch or rubberoid bituminous sealer.

Figure 25, C and D, shows "floating slab" construction, in which the slab or floor either rests on a ledge of the foundation or is independent of it. Entry for termites is provided by expansion joints. The difference in coefficient of expansion between the concrete and the filler in the expansion joints results in a pulling away of these materials from each other as soon as there is sufficient temperature change. This is also true of the supposedly impermeable fillers or caulking substances placed around utility pipes extending through a slab.

Mechanical alteration. When inspecting a building on slab it should not be assumed that all construction details are in accord with the above descriptions. For example, the possibility of a partition wall extending through the concrete to make a ground contact (fig. 26, B) should not be overlooked. Schwimmer (1955) listed the following mechanical alterations made in a duplex apartment house on a floating slab after inspection revealed that termites had entered between slab and footing.

- All wood flooring over the area of both apartments was removed.
- All wood base panels along the outer walls and inner partition walls were removed.
- All wood plates, sills, studs, or furring

found penetrating the concrete slab were cut 2 inches above the grade of the existing slab. Brick shims were inserted for support.

- All openings cut in the slab to facilitate the removal of the above wood members were treated with liquid insecticide and sealed with concrete mortar. After the concrete had set, a coating of coal tar was applied over the concrete insertions and dusted with sodium arsenite.
- All form boards in areas underlying bathtubs were removed and the open soil treated with liquid insecticide. The base and the wells of the traps were sealed with concrete, leaving the plumbing exposed. Ventilators were inserted in the openings to provide ventilation and access for future inspection.
- A coating of coal tar was applied at the junction of the concrete slab and the footing, and then dusted with sodium arsenite.
- Six-inch base panels were fitted throughout both apartments and screwed in place to permit easy removal if necessary.

Although no cracks or fissures were found in the main slab, a 1½ inch mastic coating was laid over the entire floor area in order to make up the deficiency caused by removing the wood floor. The floors were then finished with asphalt-tile covering.

Soil treatment. Treat soil under the slab by vertical drilling through the slab, or by horizontal rodding through the footing (page 43). Where a waterproofing membrane exists below the slab, it will be damaged by the vertical drilling, so if dampness is a problem the drilled holes should be sealed with a waterproof material.

Soil should be trenched and treated outside the foundation with an insecticide emulsion. Slabs of porches, stoops, or breezeways can be drilled and treated, or a strip of the slab can be broken out along the foundation and the soil treated with liquid insecticide, after which the strip can be repoured with concrete.

Procedures for wood-soil contacts

Contact between structural wood and soil seldom occurs in modern buildings, but is frequently found in older structures and sometimes in do-it-yourself construction. Some common locations for wood-soil contacts, and recommended procedures for alteration and control, will be discussed in this section.

Exterior stairs of stucco-frame construction

Figure 26, A, is a side view of an entrance stairway with stucco-covered buttresses and with the sill resting on the soil. The wood-on-ground features of this construction result in extreme termite hazard.

Mechanical alteration. Cut off lower parts of all structures so a concrete foundation not less than 6 inches high can be constructed and a new sill installed on top of the foundation. If slab is poured under entire stairway, check the bond between slab and stucco and install a curb or flash wall on the outside of the stucco if the bond is broken.

No other type of treatment is required if proper reconstruction has been made.

Partition wall extending through concrete slab

Figure 26, B, represents a stud-and-plaster partition wall extending through a concrete slab floor, leaving the wood still in direct contact with the soil. This is a common construction error in older buildings and results from building the partition wall and pouring the concrete later.

Mechanical alteration. Raise the wall (page 37) and install a concrete foundation or footing to raise the sill 6 inches above the slab.

Soil treatment. Thoroughly treat soil where the sill has been removed. If the mechanical alteration is not made, treat soil through a series of holes drilled through the concrete floor on each side of the partition wall.

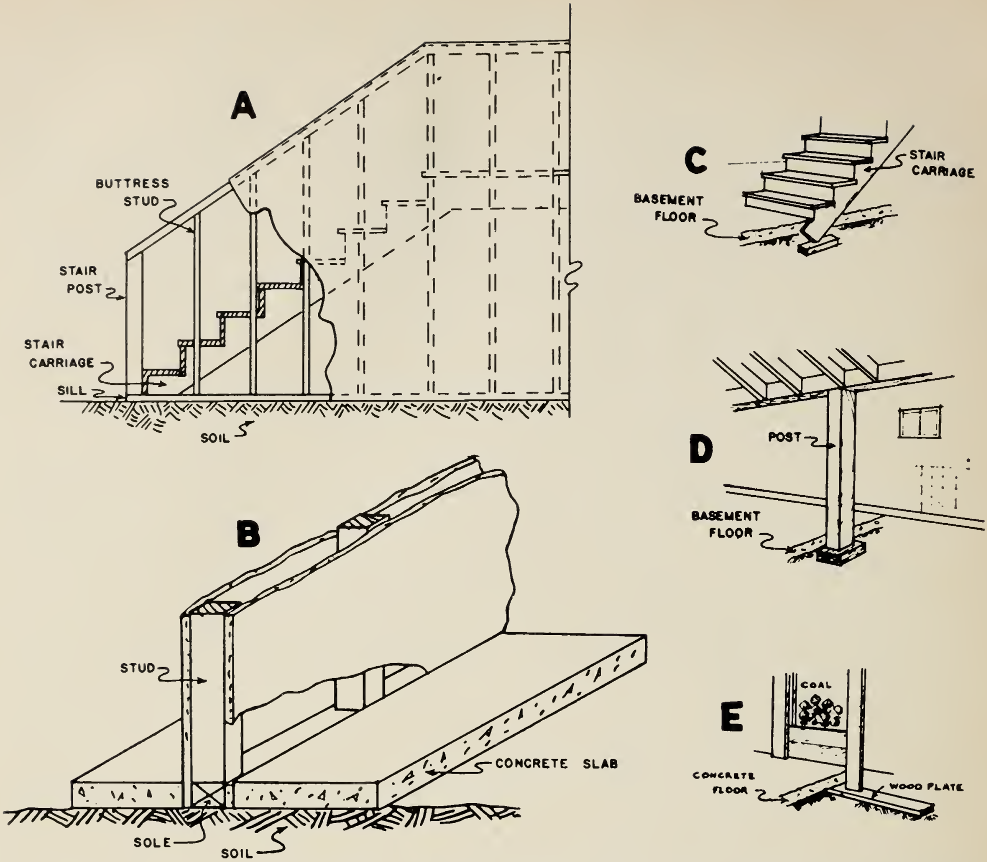

Fig. 26. Common wood-soil contacts: A. exterior stairs of stucco-frame construction; B. partition wall extending through concrete slab; C, D, E. typical examples of wood-soil contact in basements. (From Heal, 1951.)

Wood treatment. If no mechanical alteration is made, supplement the soil treatment by drilling small holes through the stucco (or other type of wall) and flood the spaces between the studs with a liquid insecticide so it will soak down into the sill and around the ends of the studs, as well as into any shrinkage cracks between the sill and the concrete slab.

Wooden posts, stairs, and coal bin in basement

Figure 26, C, D, and E represent minor construction details that commonly occur in basements where a concrete floor has been poured after wood was in place, thus covering wood in contact with soil.

Mechanical alteration. Cut all wooden parts off at a line above the basement floor and remove all wood from below the floor, closing the opening with concrete. To better distribute weight on the floor, it is best to install a concrete cap at least 4 inches high under the posts and a solid concrete bock under the main support posts. It may be necessary to shore up (support) the post and the stair before cutting the bottoms off.

Soil treatment. Treat the soil with a recommended liquid insecticide wherever wood has been removed.

Part 5. CONTROL OF DRYWOOD TERMITES

. . . the drill-and-treat method
. . . pentachlorophenol emulsion
. . . fumigation
. . . residual protection

Controlling drywood termites in buildings differs from controlling subterranean species because procedures for isolating the building from termite attack are not applicable. Attic and foundation vents of a mesh-size small enough to keep out termites are unsatisfactory as they become clogged with cobwebs and debris. The drywood termite also has many other avenues of entry—exterior cracks, crevices, and nail holes, under siding, directly through the shingles of shingled roofs, or between shingles and sheathing, etc.

Once a pair of reproductives of *Incisitermes minor* enters an attic in southern California the insects crawl about extensively and may bore directly into the wood, or they may enter via cracks in wood or crevices between sheathing and rafters, between rafter ends and a plate or ridgepole, between the plates and studding ends, between siding and studding, between building paper and studding or rim joists, or, in the substructure, between mudsills and foundations, to mention only a few of the possibilities. Snyder (1954) states that about 90 per cent of the infestations begin in some crack in the wood or joints. *I. minor* may also be in the lumber used for construction.

The colony-founding pair will deposit a frass made up of fine wood particles at the opening of their entrance holes. After the pair has hollowed out an oblong or pear-shaped cell the entrance is sealed with a brownish plug made of wood fragments and oviposition commences (fig. 10).

Behavior of *Cryptotermes brevis* is similar to that of *Incisitermes minor*. Like *I. minor*, *C. brevis* is able to tunnel into wood from the surface, if necessary. Coaton (1948*a*) states that if the wood is protected by oil paint, *C. brevis* will invariably enter it through a crack or joint or from an unpainted surface. For example, painted doors may become infested through the lower unpainted edge or the keyhole.

Control methods for drywood termites depend primarily on the extent of infestation. If it is sufficiently localized and does not appear to extend into the walls, inaccessible parts of the attic, etc., treatment may be different than if it is widespread and partly inaccessible. In the latter case fumigation, which is expensive, is the only practicable procedure. In borderline or uncertain cases less expensive, although less effective, control procedures may be indicated. The attic can then be dusted to lessen chances of reinfestation.

The drill-and-treat method

Termite galleries are located by probing suspected timbers with some sort of sharp instrument, and ¼-inch holes are drilled in the infested wood member at about 1-foot intervals. When the operator believes he has drilled a sufficient number of holes in an infested area, he may blow an insecticide dust, such as "Kali-dust" (50 per cent calcium arsenate) into the gallery by means of a "Kaligun" (fig. 27) or he may inject a liquid fumigant. An ounce of dust is enough for 15 to 30 holes; too much dust may plug the galleries and decrease the effectiveness of the treatment (holes are plugged after treatment). About one-

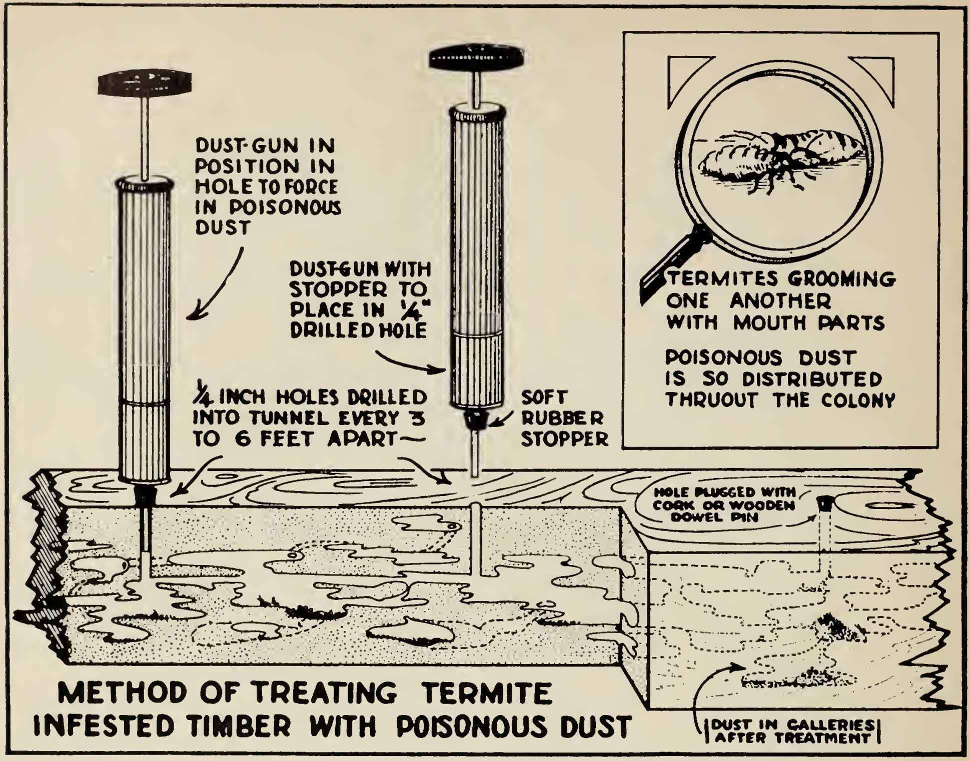

Fig. 27. Injection of poisonous dusts into drywood termite galleries. (From Light, *et al.*, 1930.)

third of a teaspoon of liquid fumigant, usually a mixture of ethylene dibromide and DDT in a petroleum solvent of high flash point, is used per hole; an entire gallery system usually requires from 0.5 to 2 tablespoonsful of liquid. A quart-size injector, pressurized with a small CO_2 bomb is commercially available, but liquid fumigants can also be satisfactorily applied with a small spring oiler or other low-pressure oil can. (Ethylene dibromide fumigants should be used only by experienced pest-control operators.)

Hassler (1955) stated that when treating wood in which it is not desirable to drill, one or two coats of ethylene dibromide solution, applied with a paintbrush, is often effective.

Randall and Doody (1934) found that when dust-treated wood was split open after treatment it could be seen that the insecticide had traveled a great distance in the galleries and, in addition, had been widely distributed by termites carrying the dust about from place to place on their tarsi. Some termite operators believe that the gas released by liquid fumigants is more widely distributed throughout the system of galleries. Gas has the disadvantage of not providing prolonged residual effectiveness, although the small concentration of DDT in the ethylene dibromide solution provides for some residual effect in those portions of the galleries contacted by the injected liquid. Liquid fumigants are now used by most operators treating for drywood termites.

An examination of the records of four termite operators in southern California revealed that many attics of houses treated for drywood termites were reinfested within a few years, particularly when treated by the drill-and-treat method (Ebeling and Wagner, 1964). Even though some termites survive a treatment it is not a total failure, for infestation and future damage will be greatly diminished by expert treatment.

Pentachlorophenol emulsion

Ebeling and Wagner (1959*b*) applied a proprietary mayonnaise-type emulsion of pentachlorophenol (Woodtreat-TC) (page 40) to wood members infested with drywood termites in 14 attics and 3 garages. Infested areas varied from 2 or 3 to 10 or more, and were sometimes found throughout the entire attic or garage. From ¾ to 2 gallons of emulsion was used per structure depending on the extent of the infestation. Emulsion was applied with a paintbrush or caulking gun. In attics, newspapers were first laid down to catch any dropped emulsion. Later, other newspapers were spread to catch pellets falling after treatment (indicating incomplete control). Areas were examined 1 to 2 months after treatment.

In four of the fourteen attics and in two of the three garages many pellets had fallen by the time of the first inspection after treatment; this was the result of incomplete survey of infested areas before treatment. More emulsion was applied to areas missed or inadequately treated at first application, and no fresh pellets were found after the second application.

Many termite operators have since reported success in the use of pentachlorophenol emulsion for the control of drywood termites. This material is also useful in controlling subterranean termites when applied to sills, cripples, joists, pier posts, etc. (page 40).

The brushing or caulking-gun method is more rapid and foolproof than the drill-and-treat method, because in the latter the galleries are sometimes difficult to detect. Sometimes also they are stopped up and dust or fumigants may not fully penetrate the gallery. Brushing can be done all around the suspected area, because time and expense of doing so are negligible.

Insecticide brushing is more rapid and less expensive than fumigation of an entire building and causes no inconvenience to the occupants. Also, incomplete results, or reinfestations, can be quickly and inexpensively rectified by second applications of the emulsion, whereas a second fumigation would be extremely expensive. Complete elimination of drywood termites from an entire building, however, is more apt to be obtained by fumigation.

Treatment for drywood termites sometimes involves application of Woodtreat-TC to painted wood. Some paints are not penetrated effectively, and thus surfaces painted with them should be roughed or scratched until there are breaks showing the bare wood before applying emulsion. Few or no paints, with the exception of some marine paints, will effectively adhere to areas treated with Woodtreat-TC until at least 12 to 18 months after treatment; treated areas should then be cleaned and sanded lightly before painting.

Fumigation

Fumigation is universally recognized as the most effective treatment for drywood termites. Frame houses are always covered with a gas-tight tarpaulin, usually a seven-ounce nylon coated with rubber, neoprene, or plastic. Generally, stucco structures with tile roofs are sealed with a special gas-tight paper wherever the fumigator believes it to be advisable to do so, including of course all the vents. (Fumigating should always be done by licensed pest-control operators.)

Fumigating gases most commonly used in the U. S. have been methyl bromide, sulfuryl fluoride, and acrylonitrile formulations. The gas most often used is methyl bromide. In recent years sulfuryl fluoride, said to be even more penetrating and effective against both *Incisitermes minor* and *Cryptotermes brevis* than methyl bromide (Stewart, 1957; Bess and Ota, 1960), and having the added advantage that it is not necessary to remove any furnishings from the house, has been used increasingly for fumigating drywood termites. Currently, methyl bromide costs much less.

Acrylonitrile with 30 per cent carbon tetrachloride and 30 per cent chloroform is used at 2 pounds per 1,000 cubic feet of building space for drywood termites and 3 pounds per 1,000 cubic feet for powder-post beetles. Methyl bromide is generally used at 2 pounds per 1,000 cubic feet and sulfuryl fluoride at 1 pound per 1,000 cubic feet. However, there are no rigid rules as to gas dosages and much depends on the discretion and judgment of the fumigator.

Residual protection

These control measures leave no residual protection against reinfestation by drywood termites, and drill-and-treat and painting methods protect only an insignificant part of wood surface subject to attack. Termite operators have long been aware of this, and Hunt (1949) expressed their feelings: "It is hoped that governmental agencies will recognize the need for scientific investigation of methods of prevention of infestations by *Kalotermes minor*. This is a problem of vital importance to every homeowner in the Pacific Southwest and it should be given immediate consideration."

Treated lumber or insecticidal sprays for wood framing

Garlick (1956) reported an experiment in which 15 houses had sills, studs, joists, and sheathing soaked for 10 minutes in a water-repellent preservative containing 10 per cent by weight of water repellents and "antibloomers" and 5 per cent by weight of chlorinated phenol preservatives two-thirds of which consisted of pentachlorophenol. In 8 years the plywood ceilings, kitchen door frames, interior door frames, and flooring of 12 of these houses had been attacked by drywood termites, but there was no evidence of termite or fungus attack in the treated wood.

Wolcott (1955) reported that a brush coat of a 1 per cent pentachlorophenol solution applied to West Indian birch, *Bursera simaruba* (L.) Sarg., protected this wood from attack by drywood termites (*Cryptotermes brevis*) for 11 years.

Hunt (1959) pointed out that much protection is obtained by treating framing lumber with wood preservatives, using application ranging from spraying, brush coating, or dipping to pressure treatment. Hunt also demonstrated that spraying of rough framing of houses with wood preservatives, during construction, is practical and effective in decreasing damage from drywood termites. He used 10 gallons of a 20 per cent copper napthenate solution to 90 gallons of water and in some tests added DDT or lindane.

Coaton (1948*a*) estimated the increased cost of construction in using treated framing lumber would be only 2 per cent and Hunt (1949) arrived at a similar estimate. The treatment of cut ends, notches, and bored holes at the time of construction would be important, and modern mass production makes this difficult.

In South Africa, buildings are treated for drywood termites (*Cryptotermes brevis*) by fumigating with methyl bromide (3 pounds per 1000 cubic feet for 24 hours) and accessible wood is then sprayed with a light petroleum solution of 5 per cent pentachlorophenol, or of 2½ per cent pentachlorophenol and 35 per cent zinc naphthenate. Two hundred houses were treated in this manner with excellent results.[8]

The increasing use of plywood in construction has stimulated interest in its protection against insect attack, particularly as the glue used to bind the veneers can be used as a carrier for the toxicant. Gay and Hirst (1963) have tested arsenic and chlordane as glue-line poisons to protect plywood against *Nasutitermes exitiosus* and *Coptotermes lacteus* with good results.

Experiments by R. E. Wagner using dieldrin for glue-line treatment of plywood panels showed that wood was protected against infestation by drywood termites (*Incisitermes minor*).[9] Drywood termites usually enter through cracks, nail holes, etc., or where two pieces of wood are joined together. Thus, the termites would

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[8] Correspondence of December 4, 1963 from G. A. Hepburn, Chief of the Plant Protection Research Institute, Pretoria, Republic of South Africa.

[9] Data on file in the Department of Agricultural Sciences, University of California, Los Angeles.

ordinarily contact the treated glue without damaging the surface veneer. In a mock-up building having an inner wall of treated and untreated plywood panels continuously subjected to large populations of drywood termites emerging from heavily infested walnut wood, the treated panels showed no signs of termite attack over a 6-year period.

Fluorinated silica aerogels

Highly sorptive clays, diatomites and silica gels dusted onto wood blocks protected them indefinitely against drywood termites (Ebeling and Wagner, 1959*a*, *b;* Wagner and Ebeling, 1959). The investigation which proved this led to the discovery that certain silica aerogels possessing a monomolecular layer of ammonium or magnesium fluosilicate had unique physical properties of great insecticidal value.[10]

Apparently fluoride existing as a monolayer on the silica particles can also act as a contact insecticide under damp conditions. To be insecticidal, enough silica aerogel must be deposited on a surface so that an insect crawling over it will pick up a considerable quantity on its lower body surface—for termites a barely visible film suffices.

Application of silica aerogel during construction. If silica aerogel is dusted onto wood blocks even in such small quantity that termites placed on them can survive for 2 weeks, the insects do not feed on the wood (although untreated wood is vigorously attacked). Silica aerogel is generally used at 1 pound per 1000 square feet in dusting attics for prevention of *Incisitermes minor* (Hagen). It has usually been applied from the crawl hole that provides access to the attic, by means of an electric blower that generates an air stream of high velocity (fig. 28, A). Recently some termite operators have been using water-type fire extinguishers pressurized to 100 psi instead of electric blowers to apply the dust (fig. 28, D) (Ebeling *et al.*, 1967). The unusually light weight of this dust results in an even distribution throughout the attic and into its extremities.

The success of attic dusting suggests the desirability of extending the protective film to include wall voids. This is best done during construction, after plaster lath has been installed and before plaster is applied. In residential construction, holes are made in the plaster lath about 4 feet above the floor and between every two studs (Ebeling and Wagner, 1964). The holes may be made by means of a sharp pick or a ½-inch drill. Three grams of silica aerogel are blown into each hole (fig. 28, C). If the plaster lath is already perforated there is no need to drill a hole. Even with perforated lath, the bulk of the dust deposits on the interior surface of the void or falls to the sole plate. With a "dry wall" the dust is blown in at the juncture of two sections; because there are no studs to prevent lateral movement of the dust, one hole suffices for a horizontal distance of approximately 10 feet. A tape is normally applied to cover the juncture of two sections of dry wall, so the hole is similarly covered over before the wall is painted.

Figure 28 shows three types of equipment for dusting: one for dusting attics (fig. 28, A), one for dusting wall voids, soffit voids, subcabinet voids, etc. (fig. 28, B and C), and (fig. 28, D) the previously mentioned water-type fire extinguisher which is suitable for dusting attics as well as wall voids, etc. The equipment shown in B and C was assembled from readily available parts. It has a small sand-blasting gun connected with a plastic hose to a 9-gallon plastic hopper holding 5 pounds of

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[10] Silica gels of lowest bulk density and of greatest porosity are called aerogels. The silica aerogel referred to in this paper, known as Dri-die 67,® has a density of 4.5 lb. per cubic foot, as packed. Dri-die 67 has a very low sorptiveness for water, even at high humidities. It has advantageous physical properties for dusting confined spaces and voids, and possesses an insecticidal efficiency far superior to that of hundreds of other powders tested, including many silica gels and aerogels. In this paper, wherever the term silica aerogel is used, it refers only to powders or dusts having physical characteristics and insecticidal effectiveness approximately equivalent to the above material.

Fig. 28. Equipment used in "built-in pest control" at the time of construction of a building. A. electric blower for dusting attics via the attic "crawl hole"; B. dusting subcabinet voids; C. dusting wall voids; D. a fire extinguisher for blowing insecticide dust which may be used in place of the two other dusters shown in the figure.

silica aerogel. Air is supplied by a centrally located portable compressor, and the dust is drawn from the hopper by venturi action.

Three grams of dust per inter-stud void protects wood surfaces inside the void from drywood termites. Combined with dusting of attic and underarea it should provide much protection against drywood termites, and some other cryptobiotic insects, for the life of the building.

Application of silica aerogel after construction. Most silica aerogel used for insecticidal purposes has been used for preventive dusting of attics—the dust has no effect on termites inside the wood. Therefore even after a treatment, particularly if it does not involve fumigation, there is a great likelihood that termites remain in the building even if treatment is followed by such dusting. Also, there is ample opportunity for drywood termites to enter from the exterior of the building, rather than from the attic. Thus a film of silica aerogel dust in the attic would be no insurance against a "call-back" for the termite operator. Nevertheless, dusting is justified under such circumstances because dusting limits the proliferation of existing colonies.

It has been asked if the silica aerogel will continue to protect wood covered with ordinary dust. The answer is that a heavy deposit of ordinary dust accumulates only on horizontal surfaces, and on such surfaces is itself an effective deterrent to infestation by drywood termites.

Boric acid powder

Boric acid powder has been used in attics and wall voids of wood-frame houses for cockroach control (Ebeling *et al.*, 1966) and has aroused interest in its possible effect against drywood termites. Reierson (1966) found that no feeding nor penetration of wood by drywood termite nymphs occurred on blocks of Douglas fir dusted with technical boric acid powder at the rate of ¾ pound and 1¾ pounds per 1000 square feet. In untreated controls, the termites burrowed into the wood and pushed out large piles of frass. When the 1¾ pounds per 1000 square feet dosage was used, all termites were dead in 6 days.

Boric acid powder, when freshly screened or made sufficiently flowable by means of suitable adjuvants, can be applied by means of the modified fire extinguisher shown in figure 28, D, which is now commercially available.

Part 7. CONTROL OF DAMPWOOD AND HARVESTER TERMITES

Prevention and control of dampwood termites consists of the same measures taken against the subterranean termites and dry rot: construction designed to avoid contact of wood and soil and to eliminate adverse moisture conditions, and treatment of the soil with an effective insecticide. Harvester termites are not a problem in the U.S.A. In a building, nests of termites are usually extensions of a nest system located mainly outside the building. Coaton (1958) states that regular applications of a poison bait when termites are seen will eventually eliminate an infestation both out of doors and in the building. The bait consists of mown grass chaffed into ½-inch lengths dipped in a sweetened solution of sodium fluosilicate and dried before use. This has replaced the sodium arsenate bait previously used (Coaton, 1948*b*) because of less hazard to workers and livestock. It may be necessary to continue bait treatment for several months before indoor infestations are completely eradicated. In the meantime, termites in the building can be discouraged by injecting 5 per cent BHC in kerosene into the wall voids via openings made by the termites in the plaster.

Anacanthotermes ochraceous, which attacks the straw in unbaked mud bricks in Egypt, has been controlled for at least 4 years by applying creosote to the straw used in making the bricks and the mud rendering with which the houses were covered. Surface sprays of creosote and fuel oil (1:1) provided protection for 2 years (Kassab *et al.*, 1960).

SUMMARY

Distribution and abundance of termites is determined by climate, vegetation, and edaphic factors. Termites are found in a 10°C (50°F) mean annual isotherm range north and south of the equator but only time will tell how much the protection afforded by heated buildings will enable them to extend this range.

There are at least 69 species of termites which are serious pests of buildings throughout the world. Divided into groupings of practical significance with regard to control procedures, they may be thought of as subterranean, drywood, dampwood, and harvester termites, the first two containing nearly all the economically important species.

Subterranean termites must maintain a connection with their subterranean nests and galleries in order to survive, and the principal control measures depend on isolation of the building from the ground by mechanical or chemical means. Similar methods for accomplishing this have been developed throughout the world; in the U.S.A. approved reference procedures have been suggested by the National Pest Control Association for various types of construction. To the extent that a building is constructed of chemically treated or naturally durable wood, it is protected against termites and other wood-destroying organisms.

Drywood termites remain in the area of the building in which feeding takes place. Attempts at control always involve: direct attack on the colony by injecting a poison dust or liquid fumigant into their galleries; painting or spraying infested wood with insecticides so that the toxicant may penetrate to their galleries; fumigating the building. Much protection against reinfestation can be obtained by blowing fluorinated silica aerogel dust into confined spaces such as the attic and underareas of houses and, at the time of construction, into the wall voids. The silica aerogel is effective as long as it is present.

Dampwood termites, which require close proximity to moisture, locate their colonies in damp and often decaying wood. Once established, they can extend their activities into sound, and even into relatively dry wood. They are controlled with procedures similar to those used against subterranean termites.

Harvester termites feed on grass and some species cause great destruction to buildings built of sunbaked clay bricks, which they hollow out to form nests. Others attack the straw in unbaked mud bricks. Harvester termites may be controlled by regular applications of a poison bait around the infested buildings or by applying creosote to the straw used in making mud bricks.

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WARNING!

Chemicals needed for pest control can be hazardous if improperly used. Carefully read and follow directions on the containers of all such chemicals. Use protective devices when called for on the label.

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